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The Growth and Composition of the tops of Peach Trees in Sand Culture in Relation to Nutrient-element Balance

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THE GROWTH AND COMPOSITION OF THE TOPS OF PEACH
TREES IN SAND CULTURE IN RELATION TO
NUTRIENT-ELEMENT BALANCE

by D. S. Brown

INTRODUCTION

The concept of a balance in nutrient-element relationships has evolved as the result of the frequently demonstrated interdependence of the elements in their effects on plant growth. Its significance in relation to fruit trees, although indicated, at least indirectly, by a number of investigations (e.g., 1, 2, 6, 9, 15, 16, 19) has not been fully evaluated. The objective of this investigation has been, therefore, to attain a better understanding of balance and, more specifically, to evaluate its significance with respect to the elements nitrogen, phosphorus, potassium, and calcium in relation to the growth and composition of young peach trees.

Unfortunately, perhaps, balance has been subject to a variety of interpretations, ranging from those which are quite definite in conveying the idea of a fixed proportionality to those which are indeterminate in their implication of some variable sort of equilibrium between the elements. As a consequence, the term frequently has been ambiguous. The difficulty, however, seems to have resulted not so much from the variability in the implications of the term as from its frequent use without enough definition or qualification to indicate the nature of the relationships which it was intended to describe.

In this investigation, balance is considered essentially as a modification of the principle of limiting factors applied to nutrient-element relationships. In applying this principle it is obvious that the degree of effectiveness of the nutrient-element supply is limited ultimately by the other environmental factors and by the genetic nature of the plant. Consequently, for a given plant in a given environment there is a maximum amount of growth which will result when none of the elements is limiting. That combination of elements in which none of them is limiting constitutes the nutrient-element supply with the highest intensity of balance. Such a supply is defined as that one with which results the maximum amount of growth possible within the limits of other environmental factors and of the genetic nature of the plant. Nutrient-

element balance, therefore, is always to be qualified, by implication at least, by the limiting effect of the genetic nature of the plant and by environmental factors other than the nutrient-element supply.

Theoretically, at least, the nutrient-element supply with the highest intensity of balance should be composed of one and only one combination of the elements, each of which is available in its proper amount. Therefore, if the supply of any given element were deviated to a level either above or below its proper amount, that element would then become limiting, and a reduction in growth should result. However, within the limits of such an altered supply of the element there also should be a maximum amount of growth which is possible, but which is less than that resulting when the supply of the element is at its proper level under conditions of the highest intensity of balance. For those conditions in which an element is limiting, a balanced nutrient-element supply of a comparatively lower intensity may be defined, therefore, as that one with which results the maximum amount of growth possible within the limits of the supply of that element.

The application of the principle of limiting factors to the concept of balance thus provides for a number of balanced nutrient-element supplies of comparatively different intensities, each of which may be defined and qualified by the factors limiting growth. Such a provision is desirable because the maximum growth which results for a given plant in a given environment when none of the nutrient elements is limiting may not be of the type or quality actually desired; for example, such growth might not be as conducive to fruitfulness as the lesser growth which would result with a nutrient-element supply of a lower intensity of balance.

I. GROWTH OF THE TREES

Materials and Methods

The experiment was conducted in a greenhouse of the Department of Horticulture at West Virginia University. One-year-old budded Elberta peach trees were planted on April 5 and 6, 1940. They were headed back at 18 inches above the bud union and all laterals were removed. The roots were

washed free of dirt and pruned just enough to permit them to fit easily into the 4-gallon galvanized garbage pails in which the trees were planted. A total of 114 trees were used, although only 108 were included finally in the experiment proper. The other six were planted so that reserves would be available if any of the trees did not start properly. The trees were remarkably uniform in appearance.

The pails, which were coated on the inside with a petroleum asphalt, were fitted with a glass tube in the bottom for drainage. The roots of the trees were covered to a point approximately an inch below the bud union with a fine quartz sand which was obtained from a glass factory in Morgantown, West Virginia. After the trees were planted the sand was flushed thoroughly with water. Rain water which was diverted from the roof of the greenhouse into a large, asphalt-lined, concrete bin was used throughout the experiment.

The pails were arranged on supports on a concrete bench in the greenhouse. The supports were so constructed that a quart Mason jar could be placed underneath the pails below the drainage outlet. At the beginning of the season the trees were arranged in tiers of four across the bench, 28 tiers in all, but later half of them were moved to another bench in the same house. At that time, they were arranged in tiers of two across each bench so as to give maximum room for each tree.

There were 54 different treatments which represent all the possible combinations of three concentrations each of nitrogen, phosphorus, and potassium and two of calcium. There were two trees per treatment. The concentrations in parts per million in the culture solutions are given in Table 1.

Stock solutions of $\text{Ca}(\text{NO}_3)_2$, CaCl_2 , $\text{Mg}(\text{NO}_3)_2$, MgSO_4 , MgHPO_4 , KH_2PO_4 , KCl , and K_2SO_4 , and Ca-acetate were used in the preparation of the culture solutions. Manganese and boron were supplied from a stock solution of MnSO_4 and H_3BO_3 . Ferric citrate was used as a source of iron.

No attempt was made to control the total concentration of the solutions. Obviously those with the highest concentrations of the elements had higher osmotic pressures than the more dilute solutions. Likewise, the initial pH of the

Table 1. The Concentrations of N, P, K, and Ca as ppm in the Culture Solutions Supplied to the Trees

Element	Concentration		
	High (H)	Medium (M)	Low (L)
N (as NO ₃)	1000* (4430)	100 (443)	10 (44)
P (as PO ₄)	200 (612)	20 (61)	2 (6)
K	800	80	8
Ca	1000	100	---

*The Magnesium concentration accompanying high N was 965 ppm, but only 185 ppm with medium and low N.

solutions, which varied from about 4.5 to 5.5, was not controlled. Once the solutions had passed through the sand, their pH approached 7.0.

For convenience the concentrations in Table 1 are designated as high (H), medium (M), and low (L). The low concentrations were planned as deficiency levels; the medium concentrations were selected as being ample for good growth, as indicated by the work of Cullinan et al. (6). No deficiency level of Ca was used. The high concentrations were chosen with the possibility in mind that they might prove to be greatly excessive.

It was not possible by the use of calcium nitrate to maintain the medium Ca level and at the same time supply all of the nitrate required in the high-N-medium-Ca series. Therefore, to supplement the N supplied as calcium nitrate, magnesium nitrate was used. It was selected instead of sodium nitrate because it was believed that any effects of Mg might be evaluated more readily than those of Na and because, in the analysis of the trees at the conclusion of the experiment, the determination of Mg would be somewhat simpler than that of Na. The use of magnesium nitrate resulted also in a high concentration of Mg. In the high-N-high-Ca series it was not necessary to use as much magnesium nitrate to

maintain the N concentration because more calcium nitrate could be used; however, the Mg level was made equal to that in the high-N-medium-Ca series by the use of magnesium sulfate. It was thought that this level of Mg might prove to be undesirably high, especially when Ca was medium, so the Mg concentration of the medium and low N series was reduced to a uniformly lower concentration throughout those two series (Table 1).

About the middle of August the supply of ferric citrate on hand was depleted; ferric sulfate, which was available, was substituted. About two weeks later certain trees began to show signs of excessive wilting. However, most of those affected wilted only during the day and recovered at night. It was learned later that peach trees in sand culture are not tolerant to ferric sulfate (5), although apple trees apparently will withstand a considerable concentration of the salt. The few trees which were most severely affected were partly defoliated at the time they were harvested, which was about ten days after the first wilting was observed. Since differences in growth were definitely established before the wilting occurred, the growth relations of the trees under the different treatments were not altered. The wilting also had no apparent effect on the results of the chemical analyses. It is believed that the trees were harvested before any major alterations in their composition had occurred.

One quart of water was applied daily to each tree until April 13, on which date a similar application of the solution containing the lowest concentrations of all four elements was begun. New shoots developed rapidly within the next two weeks. All but three of the strongest were removed from each tree, an effort being made to leave shoots which were spaced at intervals along the trunk. With but one or two exceptions, all those selected continued to develop.

On April 27 the differential treatments were assigned to the trees at random with the restriction that no two receiving the same treatment were adjacent. At first, each tree received one quart of solution daily, poured on the surface of the sand. The leachings were collected, made to volume with water, and reused once. Beginning May 31, the quart which was prepared from the preceding leachate was applied at 8 a.m.; this was followed at 4 p.m. by the application of another which was freshly prepared. Beginning in July, the largest trees were using considerable water as evidenced by the fact that the solution applied in the after-

noon did not leach through; these were given a quart of water about 2 p.m. whenever the day was bright and warm. The sand in all the pails was flushed with water once a week.

The diameters of the trunks were measured at a point just above the bud union at planting time, two measurements being taken at right angles to each other. They were measured again just before harvest. The increase in diameter was calculated, and the values for the two measurements on each trunk were averaged. The length of the shoots to the nearest five millimeters was measured a few days before the trees were harvested.

Harvest was begun on September 7 and completed on September 13. The tops of 27 trees were sampled on each of the first four days. The leaves were stripped from the shoots in the morning, after which the tops were cut off at the bud union and separated into shoots and trunks. The wood was split into small sections. The samples were put into cheese-cloth sacks and placed in a forced-draft oven at a temperature of 100-105° C. Leaf samples were left in the oven for 20 to 30 minutes, the wood samples 30 to 35 minutes. The number of samples prepared at any one time was adjusted so that a new lot could be placed in the oven when the preceding lot was removed. After the samples were taken from the oven they were hung in a drying room used by the Department of Agronomy and Genetics for drying large numbers of samples. The temperature of this room was variable between 50 and 60° C.

After all of the tops were harvested, the roots were removed from the sand, washed, and weighed. The fine roots, approximately 2 to 3 mm and under in diameter, were separated from the larger roots, which included the stock below the bud union; both lots were treated in the same manner as the tops.

All of the samples were removed from the drying room after about two weeks, then weighed.

Appearance of the Trees in the Deficiency Series

The trees as a whole grew well and reacted quickly to the different treatments, the duplicates being remarkably similar. As the season progressed, the slower growth and

the development of characteristic symptoms by the trees in the deficiency series became especially noticeable.

The low-N series: Nitrogen deficiency symptoms were apparent among the trees of the low-N series by the middle of May; the leaves were lighter green than those on trees receiving more N. The linear growth of the shoots was slow; only a few laterals to the main shoots developed. Maximum growth for most of the trees of this series was reached by the middle of July. Figure 1 shows a typical low-N tree at harvest time.

By the first of June there was a noticeable difference in condition of the foliage between the trees of the low-N series receiving high Ca and those receiving medium Ca. Both groups showed the light yellowish-green foliage characteristic of N deficiency, but the symptoms were more pronounced on those trees receiving high Ca. In addition, the margins of the leaves in this group were mottled with yellow; eventually the margins and the tips of these leaves became brown and paper thin. Many of the leaves dropped and some of the laterals of the low-N-high-Ca trees were nearly defoliated except for a few leaves near the terminals. A few shoots began to die back from the tips. None of the injury was shown by the leaves or shoots of the trees receiving low-N-medium-Ca (compare Fig. 1 and 2).

Because it was impossible to supply all of the Ca in the low-N-high-Ca series as calcium nitrate and so also maintain the low-N supply, the Ca in the N-deficient solutions was supplied as calcium chloride. Therefore it was thought that the injury might be the result of high chloride concentrations (10, 11, 12). With that in view, one half of the trees in this series was supplied, beginning on June 17, with solutions in which calcium acetate was used for the additional Ca needed to raise the level from medium to high. The #2 trees in the low-N-high-Ca series as listed in the Appendix Tables 1 to 8 received the acetate. In about two weeks there were definite indications that the progress of the injury had been stopped or at least checked considerably on the trees to which the acetate had been applied. However, those trees produced only very little or no new growth, whereas the chloride trees made some additional growth later in the season, even though they were partly defoliated. The differences between the trees were also indicated in the analyses of the tissues (Appendix Tables 3 to 8). The trees receiving the acetate were con-



FIGURE 1



FIGURE 2

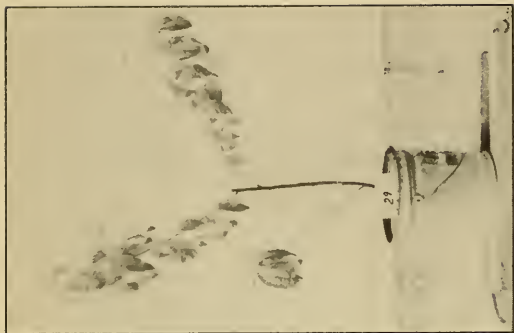


FIGURE 3

Fig. 1. Low-N-medium-Ca (LHMM). Typical low N tree. Compare with high Ca trees, Fig. 2 and Fig. 3

Fig. 2. Low-N-high-Ca (LHMH). Note defoliation which was associated with chloride concentration; this was one of the most severely defoliated trees. Compare with Fig. 1 and Fig. 3

Fig. 3. Low-N-high-Ca (LHMH). Defoliation checked by use of calcium acetate. Compare with Fig. 1 and Fig. 2

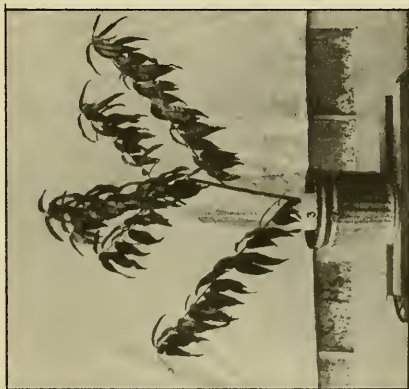


FIGURE 4

Fig. 4. Typical low P tree (MLHM). Note terminal leaves



FIGURE 5

Fig. 5. Low-K-high-Ca (MLH). Compare with Fig. 6. Note slender growth and long internodes of youngest shoots



FIGURE 87



FIGURE 86

Fig. 6. Low-K-medium-Ca (MHLM). Note relatively reduced growth compared with tree in Fig. 5

Fig. 7. Showing shot-hole appearance of leaves from low-K-high-Ca trees

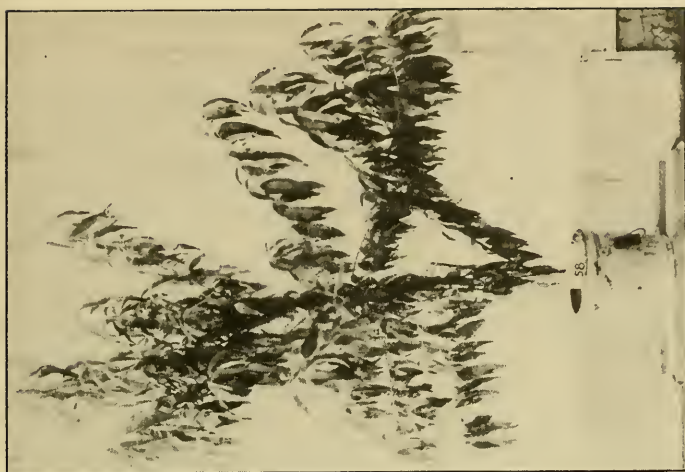


FIGURE 8

Fig. 8. One of the better trees in the medium N series (MHM). Compare with Fig. 9

Fig. 9. One of the better trees in the high N series (HHM). Compare with Fig. 8



FIGURE 9

siderably lower in N and P, but not consistently lower in K, Ca, or Mg. (See Figs. 2 and 3 for comparison of low-N-high Ca trees with and without calcium acetate as they appeared at harvest time.)

It should be noted that the trees receiving high Ca in the medium-N series were supplied with almost as much calcium chloride as those which were injured in the low-N series. However, the medium N trees showed no signs of the injury. Apparently, the injurious effect of the chloride was offset by medium N.

The low-P series: Symptoms of phosphorus deficiency developed more slowly than those of N deficiency. Distinct symptoms of P deficiency were not evident on the trees of the low-P series until mid-July. The leaves of these trees were a dull, somewhat purplish green. The terminal leaves were leathery in texture; their shape was long and narrow; they were flat and unwrinkled, extending stiffly at right angles to the axis of the shoot (Fig. 4). The shoots, which were stiff and woody, were short and only slightly branched. Maximum growth was attained in most of the low-P trees by mid-July.

The low-K series: By the middle of July, the youngest leaves of the low-K trees were smaller than comparable leaves on trees receiving more K. A few of the terminal leaves were slightly rolled. The newer shoot growth was long and slender (Fig. 5). The foliage of the low-K-high-Ca trees became marked in the interveinal areas by small necrotic lesions which dropped out and gave a shot-hole appearance to the leaves (Fig. 7). The necrosis did not appear when low K was accompanied by medium Ca, low P, or low N. The low-K-medium-Ca trees made less growth than those receiving low-K-high-Ca (Figs. 5 and 6); the reduced growth of the low-K-medium-Ca trees was especially noticeable in the high-N series. Maximum growth on those trees was reached by mid-June, whereas other low-K trees continued growth until harvest. When the P supply as well as K was deficient, the trees showed only symptoms of P deficiency.

Measurements of Growth

Data for the length and the dry weight of shoots are presented in the text in Table 2, which is a summary of the data for the measurements as presented for individual trees

in Appendix Table 1.* The summary was made by averaging the data for each of the primary treatments, N, P, K, and Ca, and for their interactions, NP, NK, PK, NCa, PCa, KCa, NPCa, NKCa, and PKCa. To obtain the averages, the data for the 108 trees in the experiment were arranged in groups, each of which included the figures for those trees receiving a particular level of one element, or the particular levels of more than one element in the case of the interactions. The data for each group were averaged to obtain the summary data for those trees receiving the treatment common to that group. Thus, to obtain the averages for high, medium, and low N the trees were divided into three groups of 36 trees, one for each of the levels of N; averages for each of the three levels of P and K were obtained from similar groups of 36 trees. For Ca there were two groups of 54 trees each, one for each of the two levels of that element.

The number of trees included in each average for the interactions depended upon the number of elements considered in the interaction and the levels at which each was supplied. Thus, for the NP interaction involving two elements each with three levels of supply, there were 9 groups of 12 trees each, representing those groups of trees receiving high-N-high-P, high-N-medium-P, high-N-low-P, medium-N-high-P, etc. Similarly, the averages for the NK and the PK interactions were obtained from groups of 12 trees each, with a total of 9 groups for each interaction. For the NCa, PCa, and KCa interactions, two elements also were involved, with Ca at two levels of supply and the others at three, so that there were 6 groups of 18 trees from which the averages were obtained. For each of the interactions NPCa, NKCa, and PKCa, there were 18 groups of 6 trees each for which averages were obtained.

Table 2 is in effect a series of subtables each of which is designated by the letter or letters of a primary treatment or interaction. The averages for the primary treatments indicate the general effects of each element individually. Their interactions indicate the manner in which the individual effects were modified by the effects of the other elements. If, for example, it is desired to determine the effects of N,

*Data for measurements of trunk diameters, dry weight of trunks and roots, and dry weight per unit length of shoots also are presented in Appendix Tables 1 and 2. Only the data for the length and dry weight of shoots are used in the discussion, since they are, for the most part, representative of the other measurements of growth.

Table 2a. Total Length and Dry Weight of Shoots. Averages for Primary Treatments and their Interactions

Treatment		Total Length of Shoots	Dry Weight of Shoots	Treatment		Total Length of Shoots	Dry Weight of Shoots
Element	Conc.	cm	gm	Element	Conc.	cm	gm
N	H	641	59.5	NCa	HH	753	63.7
	M	957	109.9		MH	1026	113.5
	L	184	13.7		LH	194	12.9
P	H	812	79.2		HM	530	55.4
	M	742	79.8		MM	889	106.3
	L	228	24.1		LM	174	14.6
K	H	688	77.8	PCa	HH	918	85.7
	M	667	70.9		MH	811	79.1
	L	427	34.4		LH	243	25.3
Ca	H	657	63.4		HM	707	72.7
	M	531	58.7		MM	674	80.5
NP	HH	882	77.2		LM	212	23.0
	HM	810	75.8	KCa	HH	642	66.3
	HL	232	25.5		MH	744	75.9
	MH	1388	149.5		LH	587	48.0
	MM	1204	146.5		HM	734	89.4
	ML	281	33.7		MM	591	66.0
	LH	168	10.9		LM	266	20.8
	LM	213	17.2	NPCa	HHH	1089	92.4
	LL	170	13.2		HMH	940	74.4
NK	HH	843	85.4		HLH	229	24.4
	HM	701	68.2		MHH	1481	154.8
	HL	379	24.9		MMH	1279	147.2
	MH	1031	134.4		MLH	319	38.7
	MM	1114	120.1		LHH	185	9.9
	ML	728	65.3		LMH	214	15.8
	LH	190	13.7		LLH	182	13.0
	LM	188	14.5		HHM	675	62.1
	LL	173	13.1		HMM	680	77.3
PK	HH	958	102.7		HLM	234	26.7
	HM	910	90.7		MHM	1294	144.2
	HL	569	44.3		MMM	1129	145.8
	MH	859	103.8		MLM	243	28.8
	MM	852	95.8		LHM	151	11.9
	ML	516	40.0		LMH	213	18.5
	LH	248	25.4		LLM	158	13.4
	LM	240	26.4				
	LL	195	19.0				

Table 2b. Total Length and Dry Weight of Shoots. Averages for Primary Treatments and their Interactions

Treatment			Treatment		
Element	Conc.	Length of Shoots cm	Element	Conc.	Length of Shoots cm
NKCa	HHH	813	PKCa	HHH	928
	HMH	815		HMH	1045
	HLH	630		HLH	783
	MHH	912		MHH	772
	MMH	1210		MMH	930
	MLH	957		MLH	730
	LHH	201		LHH	226
	LMH	206		LMH	256
	LLH	174		LLH	249
	HHM	874		HHM	988
	HMM	587		HMM	776
	HLM	128		HLM	355
	MHM	1150		MHM	946
	MMM	1017		MMM	773
	MLM	499		MLM	302
	LHM	180		LHM	269
	LMM	170		LMM	225
	LLM	172		LLM	142
Dry Weight of Shoots gm			Dry Weight of Shoots gm		
NKCa	HHH	74.5	PKCa	HHH	96.3
	HMH	74.7		HMH	99.5
	HLH	42.0		HLH	61.3
	MHH	111.3		MHH	79.9
	MMH	138.6		MMH	100.7
	MLH	90.7		MLH	56.8
	LHH	13.0		LHH	22.7
	LMH	14.4		LMH	27.4
	LLH	11.4		LLH	25.9
	HHM	96.3		HHM	109.1
	HMM	61.9		HMM	81.8
	HLM	7.8		HLM	27.2
	MHM	157.5		MHM	127.6
	MMM	121.5		MMM	90.8
	MLM	39.8		MLM	23.2
	LHM	14.3		LHM	31.5
	LMM	14.6		LMM	25.4
	LLM	14.8		LLM	12.0

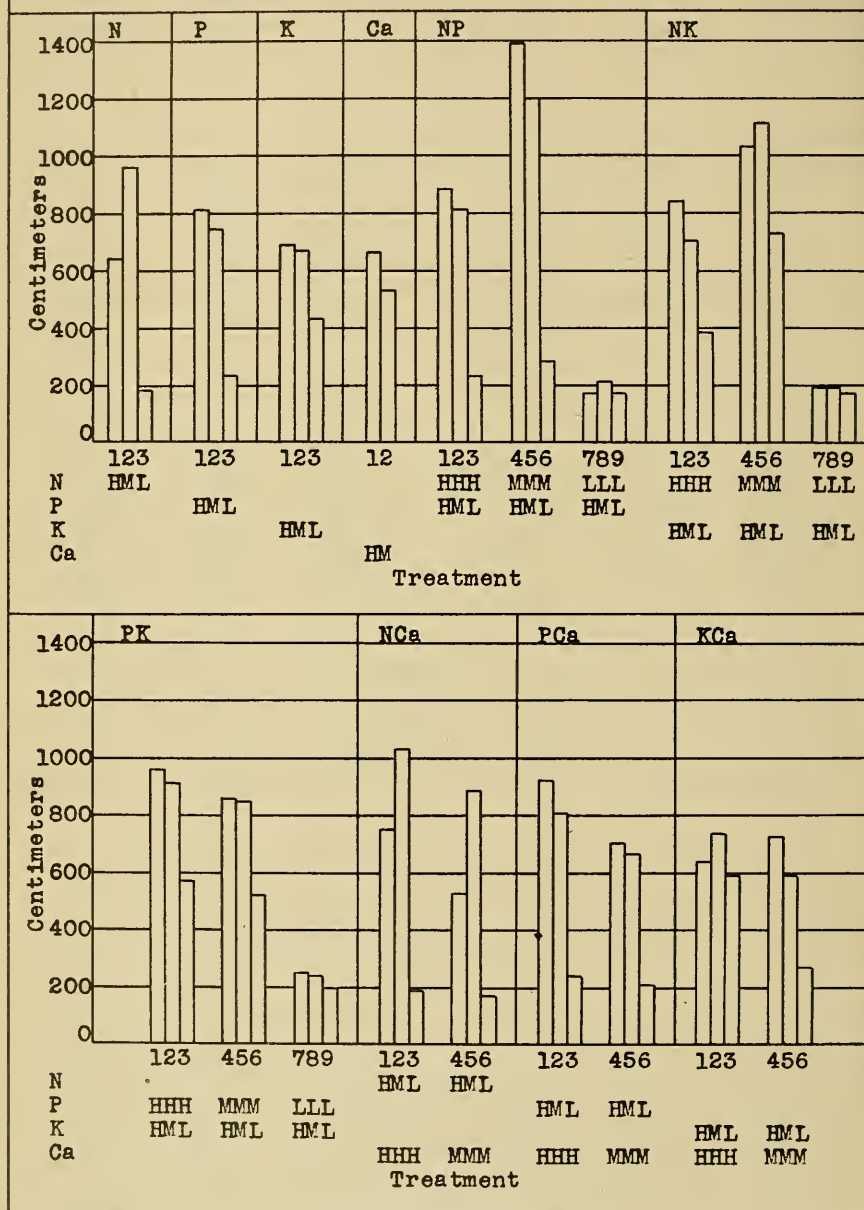
the data designated by N are examined first. Then to determine in what manner, if any, P modified the general effects of N, the NP group is considered. By examining the NPCa group it is possible to determine whether or not the relationships of N and P were different at the two Ca levels.

The data for the dry weight and the total length of shoots from Table 2 are also presented in Graphs 1 and 2, which are composed of a series of subgraphs corresponding to the primary treatments and their interactions with the exception of the higher interactions, NPCa, NKCa, and PKCa.

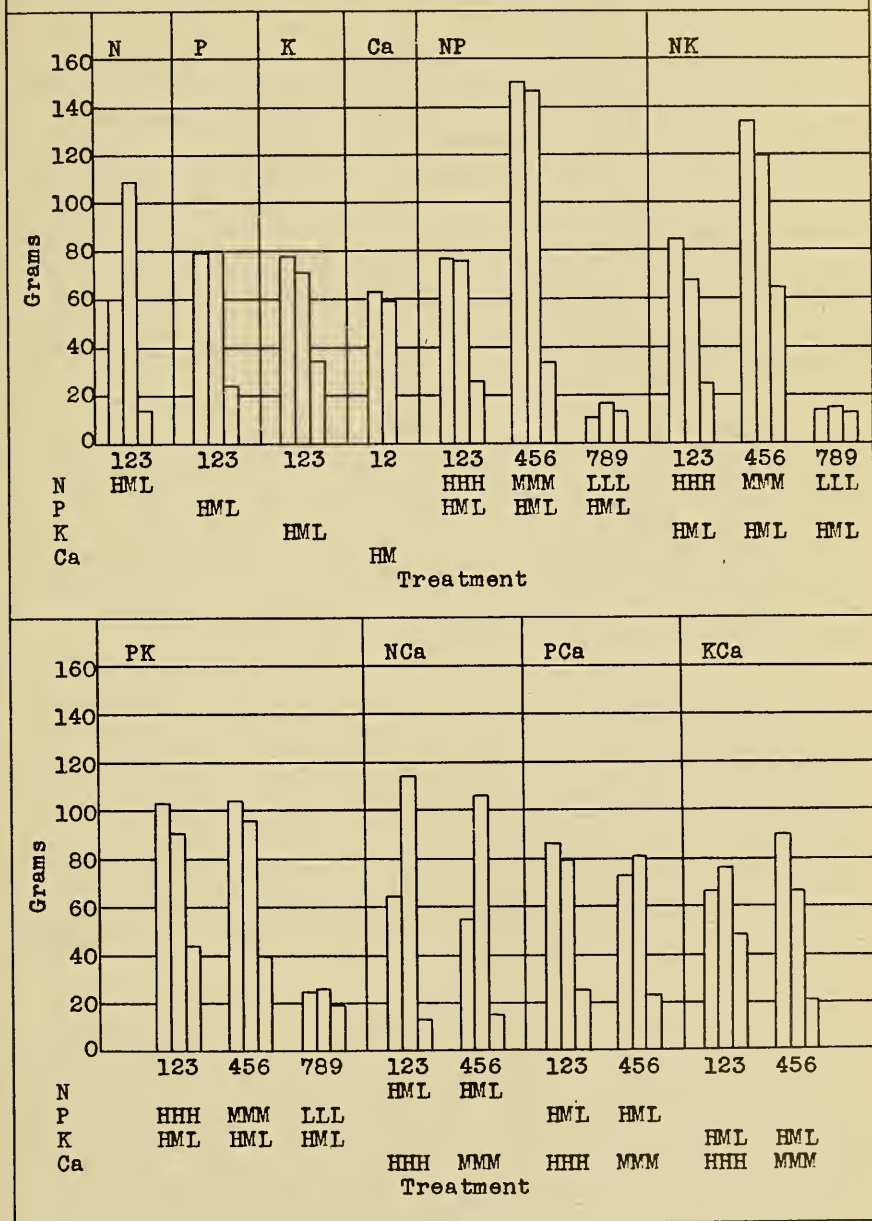
The Effects of N: The average effects of N are apparent in subgraph N, Graphs 1 and 2. Growth (dry weight and total length of shoots) was at a maximum when N was medium; it was least when N was low and intermediate when N was high (see also Figs. 1, 8 and 9). The effects of N were comparatively the same regardless of the supplies of P, K, or Ca (Graphs 1 and 2, NP, NK, bars 1:4:7, 2:5:8, 3:6:9; NCa, bars 1:2:3, 4:5:6); that is, regardless of P, K, or Ca, growth was always at a maximum when N was medium.

The intermediate amount of growth with high N indicates

Graph 1. Total Length of Shoots. Averages for Primary Treatments and their Interactions



Graph 2. Dry Weight of Shoots. Averages for Primary Treatments and their Interactions



that that level of N was excessive. Two other factors, however, may also have contributed to this result. First, the concentration of magnesium was higher, and second, the total concentration of the solutions was greater in the high than in the medium-N series. If these factors had been of primary importance in limiting the growth of the high-N trees, it seems likely that they also should have altered the effects of variations in the supplies of other elements, so that the growth within the high and the medium-N series as affected by other elements would also have differed markedly. However, the effects of other elements on the growth within the two series were fundamentally similar. Therefore it seems likely that any limiting effects of the magnesium supply or of the total concentration of the solutions were of a secondary nature and, if anything, merely intensified the limiting effect of the high N.

Nitrogen evidently was the most important of the elements as a determinant of growth. The others became important only as they influenced growth within the limits of the N supply. As a result, the intensity of balance in the nutrient-element supplies was dependent first on N. The solutions with the highest intensity of balance obviously were among those of the medium-N series, since maximum growth resulted under conditions of medium-N.

The Effects of K and Ca: K and Ca were so markedly interdependent in their effects on growth that they must be considered together. Consequently their effects are shown best by the KCa, NKCa, and PKCa interactions in which both elements are included as variables. Examination of the averages for those interactions shows that from the standpoint of maximum growth, two combinations of K and Ca were of nearly equal effectiveness. Those combinations were high-K-medium-Ca and medium-K-high-Ca (Graphs 1 and 2, KCa, HM, and MH; Table 2, NKCa, PKCa).

A more detailed consideration of these relationships can be approached in two ways: first, as to the effects of an increasing K supply when Ca was at a given level, and second as to the effects of an increasing Ca supply when K was at a given level. Thus, using the first approach, when Ca was medium, an increase in the K supply from medium to high resulted in an increased growth, but when Ca was high, it resulted in a decreased growth (Graphs 1 and 2, Table 2, KCa). On the other hand, an increase in K from low to medium resulted in an increased growth at both levels of Ca;

however, the increase was comparatively greater at medium than at high Ca. Evidently, any increase in K was most effective in promoting growth when Ca was medium.

The intensity of the effects of increasing K appear to have been influenced also by the N supply (Table 2, NKCa). Increase in growth with increasing K was comparatively greater at high-N-medium-Ca than at medium-N-medium-Ca. Apparently, under the conditions of medium Ca, the high level of K was more favorable, relatively, to growth at high than at medium N. Under conditions of high Ca, also, the high level of K was comparatively more favorable to growth at high N. This effect is indicated by the fact that the depression in growth which resulted with high K at medium-N-high-Ca was not shown at high-N-high-Ca; under the latter conditions, therefore, high K was less detrimental (comparatively beneficial) since it did not decrease growth as at medium-N-high-Ca. It is possible, of course, that K with either level of Ca was comparatively more favorable to growth at high N because it reduced or offset any deleterious effects of the higher Mg supply which accompanied high N; perhaps, if the Mg supply had been the same with high and medium N, there would have been no apparent difference in the intensity of the effects of increasing K. At low N the effects of K were minimized, since growth was so limited by the N deficiency; maximum growth within the limits of low N usually resulted, however, when K was medium.

The relations of K and Ca will now be considered from the other point of view, that of the effects of increasing Ca when K was at a given level. When K was low, growth increased markedly with an increase in the Ca supply (Graphs 1 and 2, Table 2, KCa). A similar though less pronounced increase in growth with increasing Ca resulted when K was medium. When K was high, however, growth decreased with increasing Ca.

As with the effects of increasing K, the intensity of the effects of Ca also appear to have been affected by the N supply (Table 2, NKCa). The increase in growth which resulted with increasing Ca at both low and medium K levels was more pronounced when N was high than when N was medium. The decrease in growth with increasing Ca at high K was relatively less when N was high so that comparatively, high Ca was less detrimental (relatively more beneficial) to growth at high-N-high-K than at medium-N-high-K. Thus, at all three levels of K, high Ca tended to be more favorable, rela-

tively, to growth when N was high than when N was medium. It is possible, however, that the intensity of the Ca effects was modified not so much by the high N level itself as by the higher Mg supply which accompanied high N. At low N the effects of Ca were minimized by the marked limiting effect of the N deficiency.

The effects of both K and Ca and their interrelations were not altered appreciably by the level of the P supply (Table 2, PKCa).

As determinants of growth, K and Ca apparently were next to N in importance. The growth which resulted within the limits of any level of N was determined by the relationship between K and Ca. The highest intensities of balance with respect to those two elements occurred with high-K-medium-Ca and medium-K-high-Ca, the combinations which resulted in maximum growth. The lowest intensities of balance with respect to K resulted when K was low; however, the intensity of balance at low-K-high-Ca was greater than at low-K-medium-Ca.

The Effects of P: The growth of the trees receiving solutions deficient in P was much less than that of trees supplied with higher levels of that element (Graphs 1 and 2, Table 2, P). There was no significant difference in growth between the trees receiving medium and high P. Apparently, the medium P supply was sufficient with respect to maximum growth.

The effects of P were not altered appreciably by N, K, or Ca (Graphs 1 and 2, Table 2, NP, PK, PCa, NPCa, PKCa). It is perhaps worthy to note, however, that when both K and Ca were high there was an indication that growth was greater at high than at medium P (Table 2, PKCa, HHH:MMH); the difference is not great enough, however, to be more than indicative of a possible trend. It will be shown later that the quality of growth at the two higher P levels differed even though the quantity was practically the same.

As a determinant of growth, P was apparently the least important of the four elements used as variables. The lowest intensities of balance with respect to the P supply resulted when P was low. On the other hand, the highest intensities with respect to that element resulted when its supply was either medium or high. No real distinction between medium and high P as to their influence on the intensity of balance

is possible, since there was no significant difference in growth at those two levels of P. Practically, therefore, medium and high P could be interchanged without altering appreciably the intensity of balance with respect to growth.

Balance with respect to N, P, K, and Ca: Because of the K-Ca effects, there were two combinations of N, P, K, and Ca which were practically equal as to intensity of balance. Within the limits of medium N, these combinations were: medium-N-medium-P-high-K-medium-Ca and medium-N-medium-P-medium-K-high-Ca. These combinations represent the nutrient-element supplies with the highest intensities of balance among all the solutions used. Two other combinations which had a somewhat lower intensity of balance in comparison to the first two were: medium-N-medium-P-medium-K-medium-Ca and medium-N-medium-P-high-K-high-Ca. The differences between these four combinations are indicated by the averages in Table 2, NKCa. Although these averages do not indicate any effects of P, they can be used for comparing the effects of the complete nutrient-element combinations because growth was determined primarily by N, K, and Ca, and, comparatively at least, the effects of those elements were not altered significantly by P.

Similar combinations of P, K, and Ca with high N represent the solutions with the highest intensities of balance within the high N series. They all were, however, of a comparatively lower intensity of balance than those of the medium N series. Within the limits of high N, the combination high-N-medium-P-high-K-medium-Ca had the highest intensity of balance. High-N-medium-P-medium-K-high-Ca and high-N-medium-P-high-K-high-Ca were practically the same in their effects on growth. High-N-medium-P-medium-K-medium-Ca had a definitely lower intensity of balance than the other three combinations (Table 2, NKCa).

It should be noted that since high P did not result in growth significantly different from that at medium P, the high P values could be substituted for medium P in the above combinations (both those at medium and at high N) to produce nutrient-element supplies practically equal to them as to the intensity of balance, at least in so far as growth is concerned.

Of all the combinations used, the solutions with the

lowest intensities of balance were those in which the supplies of either N, P, or K were low. Growth under these conditions was so markedly limited by the deficient element that the potentialities of the supplies of the other elements could in no way be realized.

From the standpoint of maximum growth it is obvious that there were a number of the nutrient-element supplies which were quite high as to their intensities of balance, even though they varied widely as to their relative and absolute composition. Only when the supply of one or more of the elements was markedly limiting, as in the case of the low levels of N, P, or K, or the high level of N, were the intensities of balance greatly reduced.

Other Considerations Related to Growth: The relationships between the elements with respect to maximum growth may also be considered from the viewpoint that one of their number was deficient when that maximum was not attained. As long as growth was improved by an increase in the supply of a given element, that element must have been deficient relative to the supplies of the others and the growth which potentially they could support. Thus, when Ca was medium (at either medium or high N), K must have been deficient, since growth increased when K was raised to the high level. Similarly, when K was low or medium, Ca also could be considered as deficient, since an increase in the Ca supply improved growth. When Ca was high, however, K was not deficient, since the increase in K from medium to high did not improve growth; and similarly, when K was high, Ca was not deficient, since an increase in Ca to the high level did not improve growth.

Apparently there was a variation as to the intensity or degree of a deficiency. When the supply of an element was extremely low as at low N, low P, or low K, the intensity of the deficiency was comparatively high, since growth was markedly limited. However, the intensity of the K deficiency, for example, was comparatively less when K was medium (at medium Ca) than when K was low. In this instance, although growth was not markedly impaired at medium K, it still was not at a maximum, so that comparatively K was deficient even at the medium level.

It is possible, within rough limits at least, to make a distinction between the deficiencies of different intensi-

ties. Thus, deficiencies of the highest intensity which result in sharply curtailed growth may be classed as acute. Such deficiencies are the type which are most easily recognized and which usually are implied by the term "deficiency." In addition to reduced growth, the appearance of the foliage or shoots is characterized by certain symptoms typical of the deficiency. In contrast, the deficiencies of lower intensity, which comparatively may be classed as mild, are characterized only by a growth which is reduced in comparison with that which potentially could be supported by the supplies of the elements which are not deficient. Thus, for example, the deficiency of K at the low level could be classed as acute, whereas that at medium K (and medium Ca) would be mild. The line of demarcation between an acute and a mild deficiency, of course, is probably not sharp but is represented by a range in the concentration or availability in the supply of the deficient element.

At the other extreme from a deficiency is the excess of an element. The high N is an example. In such an instance the supply of an element is so great that growth is reduced as a result. Under such conditions the maximum growth which the supplies of the other elements might support can not be attained unless the element in excess is reduced.

Theoretically, at least, the milder sort of excess is likely which is the complement of a mild deficiency. In such instance the growth is reduced as a result not only of the element in excess but also of an element which comparatively is mildly deficient. Improved growth would be expected either by reducing the element in excess or by increasing the element which is deficient. The extent to which growth would be improved by either means would depend on the degree to which one element was excessive or the other deficient. In all likelihood a larger increase in growth would result from the correction of a mild deficiency than from the reduction in the supply of an element in mild excess.

II. COMPOSITION OF THE TREES

Methods

The leaf, shoot, and trunk samples were ground in a Wiley Mill in preparation for analysis. Aliquots of the ground samples were reground in a hand-operated mill before the analyses for nitrogen. The root samples were not analyzed.

The total, the water-soluble, and the water-insoluble nitrogen were determined, using the Kjeldahl method as modified to include nitrates. In order to leach out the soluble nitrogen, a sample was placed in a cotton thimble in a glass Gooch-crucible holder. The top edges of the cotton were pushed down to cover the sample, which was then leached with 200 ml of distilled water. A 1 gm sample was used for the leaves and a 1-3 gm sample for the shoots and trunks. Preliminary trials showed that this procedure was satisfactory for removing the water-soluble nitrogen. Determinations were made on both the leachate and the leached sample. Total nitrogen was determined on an unleached sample.

By adding the figures for the soluble N as determined in the leachate and the insoluble N as determined on the residue, a figure for total N was also determined. Likewise, additional values for soluble and insoluble N were calculated by subtraction of the one or the other from the total N as determined on an unleached sample. In general, the calculated and the determined values checked closely. These values were averaged according to the following formulae, which give weight to the values as actually determined:

If T, I, and S represent total, insoluble, and soluble N, respectively, as actually determined, and T', I', and S' represent the corresponding calculated values, then,

$$\begin{aligned}\text{Av. T equals } (2T \text{ plus } T')/3, \\ \text{Av. I equals } (2I \text{ plus } I')/3, \text{ and} \\ \text{Av. S equals } (2S \text{ plus } S')/3.\end{aligned}$$

Determinations of P, K, Ca, and Mg were made according to procedures in use in the soils laboratory of the Department of Agronomy and Genetics at West Virginia University. Phosphorus and magnesium were determined colorimetrically as the phosphate, calcium titrimetrically as the oxalate, and potassium as the cobaltinitrite.

The results of the analyses, expressed as a percentage of the dry weight, are presented for the individual trees in Appendix Tables 3 to 8. From these data the N, P, K, Ca, and Mg per gram of dry weight in the shoots, trunks, and leaves were calculated in terms of their microgram-hydrogen-equivalents. For each part of each tree the equivalents were summed and the percentage of each element in that sum was calculated. This is essentially the procedure used by Thomas (17) in his calculations of the NPK-unit in foliar diagnosis. In the present paper the calculation has been modified in that the equivalents are expressed on the elemental basis, not as the oxides. Also, the equivalents units include all of the elements being considered, rather than only three of them at a time. The equivalents are based on the amount of each element equivalent to one hydrogen or its equivalent in compounds such as HNO_3 , H_3PO_4 , KNO_3 , $\text{Ca}(\text{NO}_3)_2$, and $\text{Mg}(\text{NO}_3)_2$. An explanation of the calculation follows:

For any element Y,

The milligram-H-equivalents of Y per gram of dry weight equals $(\text{percent Y} \times 1000) / (\text{H-equivalent weight})$ equals percent Y x Factor.

The microgram-H-equivalents of Y per gram of dry weight equals percent Y x Factor x 1000.

The Factors for the elements considered are:

Element	Atomic Weight	Hydrogen Equivalent	Factor (1000/H.E.)
N	14.01	14.01	71.38
P	31.02	10.34	96.71
K	39.10	39.10	25.58
Ca	40.08	20.04	49.90
Mg	24.32	12.16	82.24

The percentage of insoluble N in the shoots of one tree was 0.469. Therefore its microgram-H-equivalent per gram of dry weight equals $0.00469 \times 71.38 \times 1000$ equals 334.8.

By similar calculations, the microgram-H-equivalents for the other elements were: soluble N, 259.1; P, 272.7; K, 172.4; Ca, 161.2; Mg, 97.0. The total N equals soluble plus insoluble N equals 593.9.

The sum of the microgram-H-equivalents (N plus P plus K plus Ca plus Mg) equals 593.9 plus 272.7 plus 172.4 plus 161.2 plus 97.0 equals 1297.2.

The percentage of each element in the total was: total N, 45.78; insoluble N, 25.81; soluble N, 19.97; P,

21.02; K, 13.29; Ca, 12.43; Mg, 7.48.

The sum of the percentages for N, P, K, Ca, and Mg, that is 100, constitutes the equivalents unit.

In discussing these data the percentages of a given element in the microgram-H-equivalents unit will be referred to as either the amount or the percentage of that element in the equivalents unit, or simply, in the unit.

The data for the amount of the elements in the units were averaged according to the primary treatments and their interactions; these averages are presented in the text in Tables 3, 4, and 5 for the shoots, trunks, and leaves, respectively. The data for the primary treatments and their interactions, with the exception of NPCa, NKCa, and PKCa, are also presented in Graphs 3, 4, and 5.

The Amount of the Elements in the Tops

The amount of an element in the equivalents units in the tops was determined primarily by the supply of that element. This is indicated by the fact that in the leaves, shoots, and trunks the P, K, and Ca increased as the respective supplies of those elements increased (Graphs 3 to 5, subgraphs P, K, Ca). Also, the total N in the shoots and trunks increased as the supply of N increased (Graphs 3, 4, N). In the leaves, however, it increased only with the increase in N from low to medium (Graph 5, N).

In all three parts of the trees, insoluble N was at a maximum when the N supply was medium. The soluble N, however, increased as the N supply increased. Roughly 90 percent of the total N in the leaves was insoluble in contrast to about 50 percent in the shoots and trunks. Consequently, variations in the insoluble N were reflected in similar variations in total N in the leaves, but not in the shoots and trunks. This accounts for the failure of total N to increase in the leaves with the increase to the high N supply.

Usually the leaves, shoots, and trunks differed as to the amounts of the elements within them (Tables 3 to 5), probably as a result of natural differences in their structure and functions. The amount of total N was about the same in the units for all three parts of the trees. The soluble N, however, was much smaller and the insoluble N larger in the leaves than in the shoots and trunks. The level of

Table 3a. The N, P, K, Ca and Mg in the Equivalents Units in the Shoots. Averages for Primary Treatments and their Interactions

Treatment								
Element	Conc.	Total N	Soluble N	In-soluble N	P	K	Ca	Mg
N	H	59.76	33.67	26.09	11.70	9.03	8.55	10.97
	M	51.95	24.15	27.80	11.43	10.67	19.90	6.05
	L	37.27	13.46	23.81	12.77	13.21	29.22	7.52
P	H	44.63	19.62	25.03	18.22	10.91	18.25	7.98
	M	48.34	22.35	25.99	12.45	11.54	19.39	8.29
	L	56.01	29.30	26.71	5.23	10.47	20.03	8.27
K	H	49.62	23.11	26.51	11.38	15.27	16.90	6.83
	M	48.55	22.31	26.24	11.80	10.72	20.85	8.09
	L	50.81	25.86	24.95	12.72	6.92	19.91	9.64
Ca	H	46.52	22.44	24.08	10.31	9.95	27.58	5.64
	M	52.79	25.08	27.72	13.62	11.99	10.86	10.73
NP	HH	52.49	27.47	25.02	18.78	9.23	8.48	11.03
	HM	57.94	31.24	26.70	12.53	9.73	8.63	11.18
	HL	68.84	42.30	26.53	3.79	8.14	8.53	10.71
	MH	44.79	17.67	27.11	18.43	11.57	19.30	5.91
	MM	51.54	23.01	28.53	10.94	11.32	19.98	6.23
	ML	59.53	31.77	27.76	4.93	9.12	20.41	6.02
	LH	36.62	13.73	22.89	17.47	11.94	26.96	7.02
	LM	35.54	12.81	22.73	13.88	13.57	29.55	7.47
	LL	39.66	13.83	25.82	6.97	14.14	31.15	8.08
NK	HH	59.80	32.98	26.82	11.15	12.80	7.47	8.78
	HM	59.69	32.93	26.68	11.74	9.48	8.96	10.22
	HL	59.86	35.10	24.76	12.19	4.82	9.21	13.92
	MH	51.49	22.57	28.92	10.65	15.16	17.60	5.10
	MM	49.44	21.87	27.58	10.71	10.58	22.75	6.53
	ML	54.92	28.02	26.90	12.94	6.26	19.35	6.53
	LH	37.56	13.77	23.79	12.34	17.85	25.65	6.60
	LM	36.60	12.14	24.45	12.96	12.10	30.84	7.51
	LL	37.66	14.46	23.20	13.02	9.69	31.18	8.45
PK	HH	44.21	18.10	26.11	17.47	15.27	16.44	6.62
	HM	42.75	17.72	25.03	18.37	11.22	19.87	7.78
	HL	46.95	23.05	23.89	18.83	6.24	18.42	9.56
	MH	47.97	20.97	27.01	11.59	16.30	17.28	6.87
	MM	47.24	20.92	26.32	11.93	11.37	21.03	8.44
	ML	49.80	25.17	24.63	13.83	6.94	19.86	9.58
	LH	56.68	30.26	26.41	5.09	14.24	16.99	7.01
	LM	55.66	28.30	27.36	5.11	9.56	21.64	8.04
	LL	55.69	29.35	26.34	5.49	7.60	21.46	9.77

Table 3b. The N, P, K, Ca and Mg in the Equivalents Units in the Shoots. Averages for Primary Treatments and their Interactions

Treatment								
Element	Conc.	Total N	Soluble N	In-soluble N	P	K	Ca	Mg
NCa	HH	59.61	34.54	25.06	12.19	8.21	12.89	7.11
	MH	48.81	22.40	26.40	9.67	9.24	28.17	4.11
	LH	31.15	10.37	20.78	9.07	12.41	41.68	5.69
	HM	59.90	32.79	27.11	11.21	9.86	4.20	14.84
	MM	55.10	25.90	29.20	13.19	12.09	11.63	7.99
	LM	43.39	16.54	26.85	16.47	14.02	16.76	9.36
PCa	HH	42.37	17.92	24.44	15.68	10.14	26.09	5.72
	MH	45.61	21.69	23.92	10.92	10.27	27.50	5.70
	LH	51.59	27.71	23.88	4.33	9.45	29.15	5.49
	HM	46.89	21.32	25.57	20.76	11.68	10.40	10.26
	MM	51.07	23.01	28.06	13.97	12.80	11.27	10.88
	LM	60.43	30.90	29.53	6.13	11.48	10.91	11.05
KCa	HH	46.58	22.49	24.07	9.86	13.41	24.85	5.33
	MH	44.21	19.73	24.49	10.23	10.07	29.59	5.90
	LH	48.78	25.10	23.68	10.85	6.39	28.31	5.69
	HM	52.66	23.72	28.94	12.91	17.14	8.96	8.34
	MM	52.88	24.90	27.99	13.37	11.37	12.10	10.28
	LM	52.84	26.62	26.23	14.59	7.46	11.52	13.58
NPCa	HHH	51.13	25.52	25.60	19.26	8.73	13.49	7.39
	HMH	57.27	32.07	25.21	13.82	8.70	12.78	7.43
	HLH	70.44	46.06	24.38	3.48	7.20	12.39	6.50
	MHH	43.11	16.65	26.47	16.13	10.26	26.35	4.16
	MMH	49.60	22.55	27.05	8.62	9.25	28.02	4.53
	MLH	53.71	28.02	25.70	4.28	8.22	30.14	3.66
	LHH	32.89	11.60	21.28	11.66	11.43	38.43	5.60
	LMH	29.95	10.46	19.49	10.34	12.87	41.70	5.15
	LLH	30.62	9.05	21.57	5.22	12.93	44.92	6.32
	HHM	53.86	29.40	24.45	18.28	9.74	3.46	14.67
	HMM	58.61	30.42	28.19	11.24	10.76	4.47	14.93
	HLM	67.24	38.55	28.69	4.09	9.08	4.67	14.93
	MHM	46.46	18.70	27.76	20.73	12.88	12.26	7.67
	MMM	53.48	23.46	30.02	13.27	13.39	11.94	7.93
	MLM	65.35	35.53	29.82	5.57	10.02	10.68	8.38
	LHM	40.36	15.86	24.50	23.28	12.44	15.48	8.45
	LMM	41.12	15.16	25.96	17.42	14.27	17.41	9.79
	LLM	48.70	18.62	30.08	8.72	15.34	17.39	9.85

Table 3c. The N, P, K, Ca and Mg in the Equivalent Units in the Shoots. Averages for Primary Treatments and their Interactions

Treatment								
Element	Conc.	Total N	Soluble N	In-soluble N	P	K	Ca	Mg
NKC _a	HHH	57.82	32.48	25.34	11.67	11.55	11.56	7.39
	HMH	58.03	31.92	26.11	11.93	9.03	13.43	7.59
	HLH	62.99	39.25	23.74	12.95	4.04	13.69	6.34
	MHH	50.50	23.73	26.77	9.19	12.37	24.38	3.57
	MMH	45.08	19.10	25.99	9.05	9.67	31.88	4.34
	MLH	50.85	24.39	26.46	10.79	5.69	28.25	4.44
	LHH	31.42	11.29	20.13	8.70	16.28	38.59	5.01
	LMH	29.54	8.18	21.36	9.72	11.51	43.48	5.76
	LLH	32.51	11.65	20.85	8.80	9.43	42.98	6.28
	HHM	61.78	33.48	28.30	10.63	14.05	3.37	10.18
	HMM	61.19	33.94	27.25	11.56	9.93	4.49	12.84
	HLM	56.73	30.95	25.78	11.43	5.59	4.74	21.51
	MHM	52.48	21.41	31.07	12.11	17.95	10.82	6.64
	MMM	53.81	24.64	29.17	12.36	11.49	13.62	8.72
	MIM	59.00	31.65	27.35	15.10	6.84	10.45	8.62
	LHM	43.71	16.26	27.45	15.98	19.43	12.70	8.19
	LMM	43.66	16.11	27.54	16.20	12.68	18.20	9.27
	LLM	42.81	17.26	25.55	17.23	9.95	19.38	10.63
PKC _a	HHH	42.58	17.66	24.91	14.99	13.61	23.55	5.27
	HMH	38.60	14.03	24.57	15.50	11.25	28.96	5.70
	HLH	45.95	22.09	23.86	16.56	5.57	25.76	6.18
	MHH	44.81	19.93	24.88	10.36	14.02	25.18	5.64
	MMH	42.60	18.25	24.34	10.84	10.91	29.31	6.35
	MLH	49.41	26.89	22.52	11.58	5.88	28.01	5.13
	LHH	52.34	29.90	22.44	4.22	12.58	25.79	5.07
	LMH	51.45	26.91	24.55	4.35	8.05	30.50	5.65
	LLH	50.97	26.32	24.66	4.41	7.71	31.15	5.76
	HHM	45.83	18.53	27.30	19.94	16.94	9.33	7.96
	HMM	46.90	21.41	25.49	21.24	11.20	10.79	9.87
	HLM	47.94	24.02	23.92	21.11	6.90	11.09	12.95
	MHM	51.13	22.00	29.13	12.83	18.58	9.37	8.10
	MMM	51.89	23.59	28.30	13.02	11.83	12.74	10.53
	MIM	50.19	23.45	26.74	16.08	8.01	11.70	14.03
	LHM	61.01	30.62	30.39	5.96	15.91	8.19	8.95
	LMM	59.87	29.69	30.18	5.86	11.06	12.78	10.43
	LLM	60.41	32.39	28.02	6.57	7.48	11.77	13.78

Table 4a. The N, P, K, Ca and Mg in the Equivalents Units in the Trunks. Averages for Primary Treatments and their Interactions

Treatment								
Element	Conc.	Total N	Soluble N	In-soluble N	P	K	Ca	Mg
N	H	53.86	26.46	27.40	14.31	9.23	13.81	8.80
	M	47.32	17.80	29.52	13.34	11.29	21.03	7.02
	L	37.89	8.86	29.03	15.89	13.56	24.37	8.30
P	H	42.11	15.25	26.86	19.34	11.18	19.38	7.99
	M	45.60	17.30	28.30	15.00	11.63	19.52	8.25
	L	51.35	20.56	30.80	9.20	11.26	20.32	7.87
K	H	47.57	18.82	28.75	13.35	14.35	17.52	7.22
	M	46.11	17.54	28.58	14.69	11.27	19.83	8.09
	L	45.38	16.76	28.62	15.50	8.45	21.86	8.81
Ca	H	44.99	17.48	27.51	13.72	10.99	23.33	6.96
	M	47.72	17.94	29.79	15.30	11.72	16.14	9.11
NP	HH	48.30	22.98	25.31	19.96	9.15	13.65	8.94
	HM	52.57	25.87	26.70	15.15	10.20	13.11	8.97
	HL	60.70	30.51	30.19	7.80	8.34	14.67	8.48
	MH	41.33	13.35	27.98	18.00	11.19	22.12	7.37
	MM	46.56	17.26	29.30	13.41	12.04	20.57	7.42
	ML	54.09	22.80	31.29	8.61	10.64	20.40	6.26
	LH	36.71	9.43	27.28	20.07	13.21	22.36	7.65
	LM	37.68	8.78	28.90	16.44	12.65	24.87	8.36
	LL	39.27	8.37	30.91	11.18	14.80	25.87	8.88
NK	HH	56.25	28.98	27.27	13.03	11.55	11.51	7.65
	HM	53.05	25.80	27.25	14.67	9.35	13.89	9.07
	HL	52.27	24.59	27.68	15.25	6.79	16.02	9.67
	MH	48.37	18.25	30.10	11.77	14.60	18.95	6.33
	MM	47.75	17.97	29.77	13.11	11.32	20.57	7.25
	ML	45.87	17.18	28.69	15.14	7.95	23.57	7.47
	LH	38.11	9.23	28.88	15.25	16.91	22.07	7.67
	LM	37.55	8.84	28.71	16.33	13.15	25.03	7.94
	LL	38.01	8.51	29.50	16.10	10.61	26.00	9.28
PK	HH	42.95	15.72	27.23	17.75	14.41	17.87	7.02
	HM	41.07	14.15	26.92	20.18	11.27	19.12	8.36
	HL	42.32	15.89	26.43	20.10	7.87	21.13	8.58
	MH	45.91	17.29	28.62	13.95	15.43	17.10	7.61
	MM	46.35	18.26	28.10	14.62	11.80	19.25	7.97
	ML	44.54	16.36	28.18	16.43	7.66	22.20	9.17
	LH	53.85	23.44	30.41	8.34	13.22	17.57	7.02
	LM	50.92	20.21	30.72	9.28	10.74	21.12	7.93
	LL	49.29	18.02	31.26	9.97	9.83	22.25	8.67

Table 4b. The N, P, K, Ca and Mg in the Equivalents Units in the Trunks. Averages for Primary Treatments and their Interactions

Treatment								
Element	Conc.	Total N	Soluble N	In-soluble N	P	K	Ca	Mg
N ₂ Ca	HH	53.27	27.73	25.54	14.68	8.44	16.47	7.13
	MH	46.03	17.23	28.81	11.86	10.83	25.26	6.01
	LH	35.67	7.48	28.20	14.62	13.71	28.27	7.73
	HM	54.45	25.18	29.26	13.93	10.02	11.14	10.46
	MM	48.61	18.38	30.24	14.81	11.75	16.80	8.02
	LM	40.11	10.24	29.86	17.17	13.40	20.47	8.86
P ₂ Ca	HH	40.81	14.56	26.25	18.31	11.14	22.80	6.94
	MH	44.43	17.54	26.89	14.23	11.12	23.18	7.04
	LH	49.74	20.34	29.40	8.63	10.73	24.01	6.90
	HM	43.42	15.95	27.46	20.37	11.23	15.95	9.03
	MM	46.78	17.07	29.71	15.77	12.14	15.85	9.46
	LM	52.97	20.78	32.19	9.77	11.80	16.61	8.85
K ₂ Ca	HH	45.42	17.97	27.44	13.27	13.73	20.90	6.69
	MH	44.26	16.66	27.60	13.81	11.15	23.87	6.90
	LH	45.30	17.80	27.50	14.09	8.10	25.22	7.29
	HM	49.73	19.67	30.06	13.43	14.98	14.13	7.75
	MM	47.97	18.42	29.55	15.57	11.39	15.79	9.28
	LM	45.47	15.72	29.75	16.91	8.80	18.49	10.32
N ₂ P ₂ Ca	HHH	46.58	22.57	24.01	20.29	8.53	16.92	7.68
	HMH	51.95	27.76	24.19	16.02	9.57	15.55	6.92
	HLH	61.29	32.86	28.42	7.75	7.22	16.95	6.80
	MHH	40.51	12.71	27.80	16.53	11.16	25.76	6.05
	MMH	45.84	17.45	28.39	11.45	10.82	25.39	6.50
	MLH	51.76	21.52	30.24	7.62	10.52	24.62	5.50
	LHH	35.35	8.39	26.96	18.12	13.72	25.72	7.09
	LMH	35.50	7.41	28.09	15.24	12.96	28.60	7.71
	LLH	36.17	6.63	29.54	10.51	14.46	30.48	8.39
	HHM	50.02	23.41	26.61	19.64	9.78	10.38	10.19
	HMM	53.19	23.98	29.22	14.28	10.83	10.67	11.03
	HLM	60.12	28.17	31.96	7.86	9.47	12.39	10.16
	MHM	42.15	13.99	28.16	19.47	11.22	18.47	8.70
	MMM	47.28	17.07	30.21	15.38	13.25	15.75	8.35
	MLM	56.42	24.08	32.34	9.60	10.77	16.19	7.02
	LHM	38.08	10.47	27.61	22.02	12.70	19.00	8.21
	LMH	39.86	10.16	29.70	17.64	12.35	21.14	9.01
	LIM	42.38	10.10	32.28	11.84	15.15	21.26	9.37

Table 4c. The N, P, K, Ca and Mg in the Equivalents Units in the Trunks. Averages for Primary Treatments and their Interactions

Treatment		Total N	Soluble N	In-soluble N	P	K	Ca	Mg
Element	Conc.							
NKC _a	HHH	52.81	27.03	25.78	14.24	11.23	14.55	7.17
	HMH	51.94	26.23	25.70	15.07	8.55	17.05	7.39
	HLH	55.06	29.93	25.14	14.74	5.53	17.82	6.84
	MHH	47.74	18.90	28.84	11.44	13.57	21.84	5.42
	MMH	45.80	16.46	29.34	11.39	11.09	25.55	6.17
	MLH	44.57	16.32	28.24	12.77	7.85	28.38	6.44
	LHH	35.70	7.99	27.71	14.13	16.39	26.30	7.47
	LMH	35.04	7.28	27.76	14.98	13.82	29.03	7.13
	LLH	36.28	7.16	29.12	14.75	10.92	29.47	8.59
	HHM	59.70	30.93	28.76	11.83	11.88	8.48	8.13
	HMM	54.17	25.37	28.80	14.20	10.14	10.74	10.76
	HLM	49.48	19.25	30.23	15.76	8.06	14.21	12.49
	MHM	48.98	17.61	31.37	12.10	15.63	16.06	7.24
	MMM	49.70	19.49	30.21	14.83	11.56	15.60	8.32
	MLM	47.17	18.04	29.13	17.52	8.06	18.75	8.50
	LHM	40.51	10.46	30.06	16.37	17.43	17.84	7.87
	LMM	40.06	10.40	29.65	17.68	12.48	21.04	8.76
	LLM	39.75	9.87	29.88	17.45	10.30	22.52	9.97
PKC _a	HHH	40.89	14.41	26.48	17.65	14.27	20.76	6.44
	HMH	39.77	12.84	26.92	18.68	11.54	23.04	6.98
	HLH	41.78	16.42	25.35	18.61	7.60	24.61	7.41
	MHH	43.93	17.25	26.68	13.89	14.57	20.87	6.75
	MMH	44.08	16.94	27.14	14.21	11.39	23.21	7.12
	MLH	45.28	18.43	26.85	14.61	7.39	25.47	7.26
	LHH	51.43	22.27	29.16	8.27	12.36	21.06	6.88
	LMH	48.93	20.19	28.74	8.56	10.53	25.38	6.61
	LLH	48.85	18.55	30.30	9.04	9.31	25.60	7.21
	HHM	45.02	17.04	27.98	17.85	14.56	14.98	7.61
	HMM	42.37	15.46	26.91	21.68	11.01	15.21	9.74
	HLM	42.86	15.36	27.50	21.59	8.13	17.66	9.75
	MHM	47.90	17.34	30.56	14.02	16.29	13.33	8.47
	MMM	48.63	19.58	29.05	15.03	12.21	15.30	8.83
	MLM	43.81	14.29	29.52	18.24	7.93	18.93	11.09
	LHM	56.27	24.62	31.65	8.42	14.08	14.07	7.16
	LMM	52.92	20.23	32.69	9.99	10.96	16.87	9.26
	LLM	49.73	17.50	32.23	10.90	10.35	18.89	10.13

Table 5a. The N, P, K, Ca and Mg in the Equivalents Units in the Leaves. Averages for Primary Treatments and their Interactions

Treatment								
Element	Conc.	Total N	Soluble N	In-soluble N	P	K	Ca	Mg
N	H	52.95	6.24	46.71	5.23	11.19	11.36	19.27
	M	53.49	4.95	48.55	6.07	14.61	15.45	10.37
	L	37.54	3.06	34.49	9.16	18.58	21.56	13.16
P	H	47.45	4.68	42.78	10.67	14.19	14.92	12.77
	M	48.43	4.81	43.62	6.66	14.65	15.81	14.44
	L	48.10	4.76	43.34	3.12	15.55	17.64	15.60
K	H	47.63	4.60	43.03	7.01	22.12	12.48	10.76
	M	48.51	4.72	43.80	6.16	14.36	16.98	13.98
	L	47.84	4.93	42.92	7.28	7.90	18.91	18.06
Ca	H	47.78	4.94	42.84	6.18	14.74	20.13	11.17
	M	48.21	4.56	43.66	7.46	14.85	12.11	17.37
NP	HH	53.29	6.02	47.28	8.04	11.26	10.28	17.12
	HM	52.89	5.72	47.17	5.09	11.44	10.79	19.78
	HL	52.66	6.99	45.67	2.55	10.86	13.01	20.92
	MH	52.65	4.82	47.83	10.11	13.99	14.20	9.07
	MM	55.78	5.67	50.11	5.10	14.40	14.32	10.40
	ML	52.05	4.35	47.70	3.01	15.46	17.83	11.65
	LH	36.42	3.20	33.22	13.87	17.32	20.28	12.11
	LM	36.63	3.04	33.58	9.79	18.11	22.32	13.16
	LL	39.59	2.94	36.65	3.81	20.31	22.07	14.22
NK	HH	54.08	6.23	47.85	4.94	17.72	9.30	13.96
	HM	54.44	6.60	47.84	5.23	11.46	11.08	17.81
	HL	50.32	5.90	44.43	5.52	4.39	13.71	26.06
	MH	53.52	4.47	49.06	4.87	22.95	11.03	7.64
	MM	52.79	4.76	48.03	5.35	14.65	16.75	10.46
	ML	54.17	5.62	48.55	7.99	6.24	18.57	13.03
	LH	35.28	3.10	32.18	11.23	25.69	17.11	10.69
	LM	38.32	2.80	35.52	7.90	16.98	23.11	13.69
	LL	39.04	3.28	35.76	8.34	13.08	24.45	15.11
PK	HH	46.74	4.34	42.39	10.93	21.24	11.61	9.49
	HM	47.88	4.14	43.75	9.33	14.46	15.94	12.38
	HL	47.74	5.55	42.20	11.77	6.84	17.21	16.44
	MH	47.51	4.66	42.85	7.12	22.36	12.38	10.63
	MM	48.54	4.44	44.11	6.06	14.39	16.60	14.41
	ML	49.24	5.34	43.90	6.80	7.21	18.46	18.29
	LH	48.64	4.80	43.84	2.99	22.76	13.45	12.17
	LM	49.12	5.58	43.54	3.09	14.22	18.41	15.16
	LL	46.55	3.90	42.64	3.29	9.67	21.05	19.46

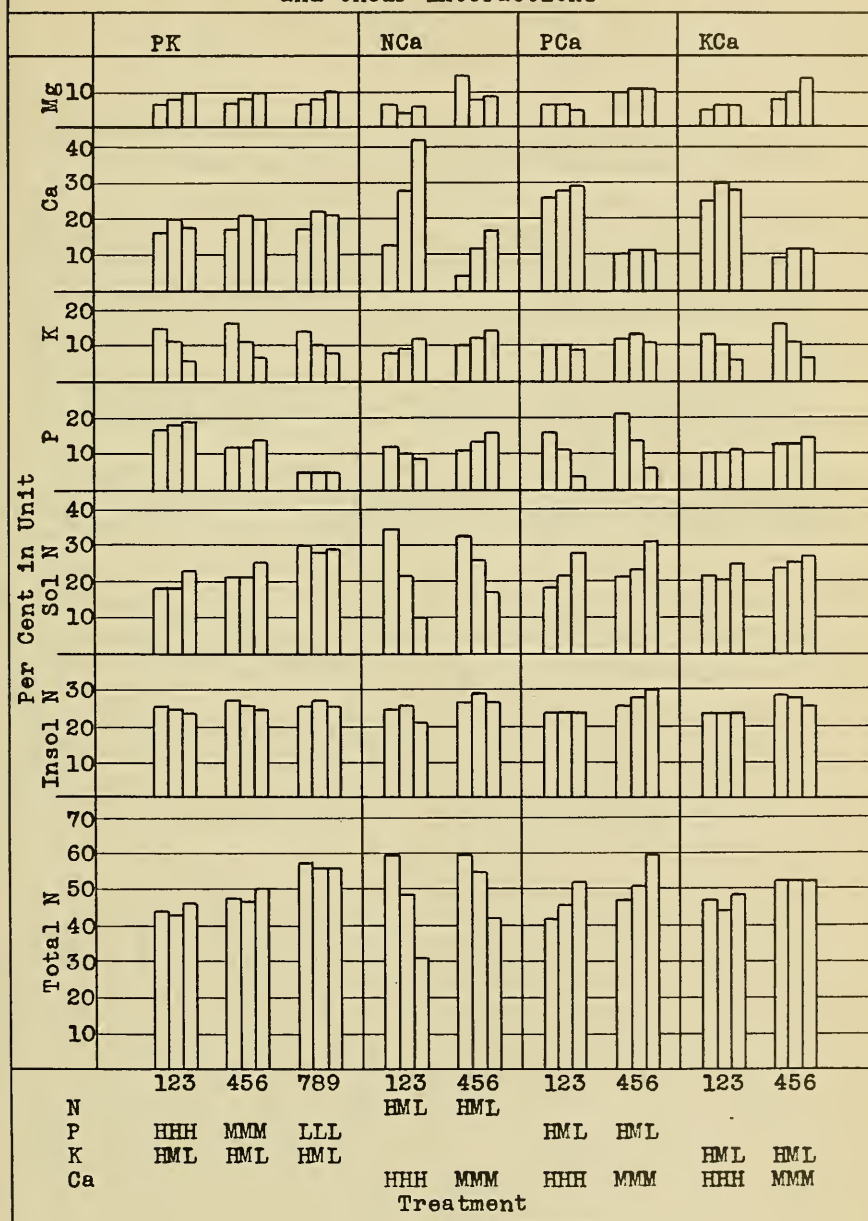
Table 5b. The N, P, K, Ca and Mg in the Equivalents Units in the Leaves. Averages for Primary Treatments and their Interactions

Treatment								
Element	Conc.	Total N	Soluble N	In-soluble N	P	K	Ca	Mg
NCa	HH	54.19	6.99	47.20	5.71	10.51	15.37	14.22
	MH	53.00	4.78	48.22	5.89	13.65	18.95	8.51
	LH	38.14	3.06	33.08	6.94	20.05	26.09	10.78
	HM	51.70	5.49	46.21	4.74	11.87	7.35	24.33
	MM	53.99	5.12	48.87	6.26	15.57	11.95	12.23
	LM	38.95	3.06	35.89	11.37	17.11	17.03	15.55
PCa	HH	48.40	4.78	43.62	9.12	14.46	18.72	9.29
	MH	48.17	4.71	43.46	6.37	14.28	19.53	11.64
	LH	46.76	5.34	41.43	3.05	15.46	22.15	12.58
	HM	46.51	4.57	41.94	12.22	13.91	11.12	16.25
	MM	48.69	4.92	43.78	6.95	15.02	12.09	17.25
	LM	49.45	4.18	45.26	3.20	15.63	13.12	18.62
KCa	HH	46.70	4.75	41.95	5.78	21.32	16.69	9.50
	MH	47.43	4.88	42.54	5.62	14.35	21.43	11.18
	LH	49.21	5.20	44.01	7.14	8.54	22.28	12.83
	HM	48.55	4.45	44.10	8.24	22.92	8.27	12.03
	MM	49.60	4.55	45.05	6.70	14.38	12.54	16.79
	LM	46.48	4.67	41.82	7.43	7.26	15.53	23.30
NPCa	HHH	55.60	6.50	49.10	8.72	10.77	13.95	10.96
	HMH	54.08	6.29	47.79	5.86	10.80	14.27	14.98
	HLH	52.89	8.18	44.70	2.56	9.95	17.89	16.72
	MHH	52.23	4.70	47.53	10.06	12.94	17.54	7.23
	MMH	55.14	4.67	50.47	4.81	13.32	17.50	9.24
	MLH	51.64	4.97	46.67	2.79	14.69	21.81	9.07
	LHH	37.37	3.15	34.23	8.60	19.67	24.68	9.68
	LMH	35.30	3.17	32.13	8.43	18.74	26.83	10.71
	LLH	35.76	2.86	32.90	3.81	21.75	26.75	11.94
	HHM	50.99	5.53	45.46	7.36	11.75	6.62	23.29
	HMM	51.69	5.15	46.54	4.33	12.09	7.31	24.58
	HLM	52.43	5.79	46.64	2.55	11.78	8.13	25.12
	MHM	53.07	4.93	48.14	10.16	15.00	10.86	10.92
	MMM	56.42	6.68	49.74	5.39	15.49	11.15	11.55
	MLM	52.46	3.74	48.73	3.22	16.23	13.85	14.24
	LHM	35.46	3.24	32.22	19.14	14.98	15.88	14.55
	LMM	37.96	2.92	35.04	11.14	17.48	17.82	15.60
	LLM	43.42	3.01	40.40	3.82	18.88	17.39	16.49

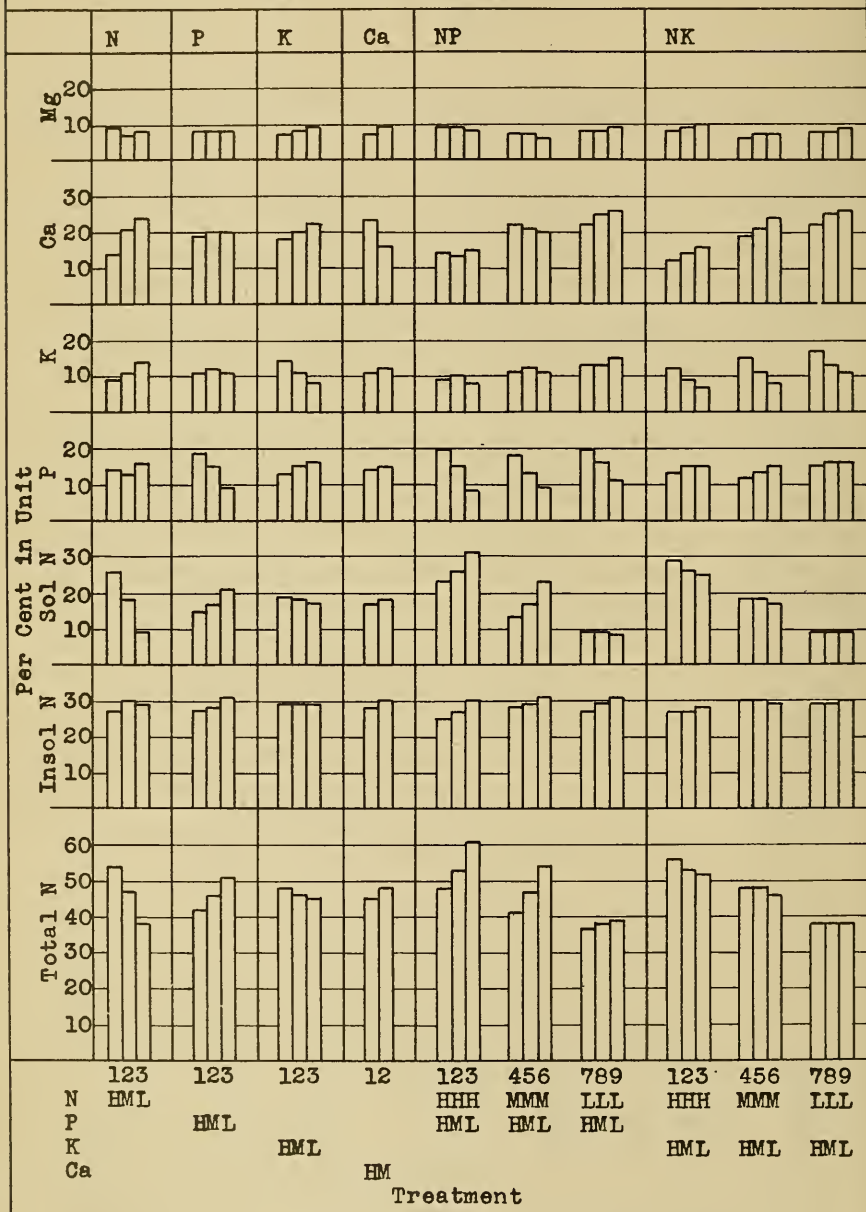
Table 5c. The N, P, K, Ca and Mg in the Equivalents Units in the Leaves. Averages for Primary Treatments and their Interactions

Treatment								
Element	Conc.	Total N	Soluble N	In-soluble N	P	K	Ca	Mg
NPKCa	HHH	52.46	6.30	46.17	4.94	16.64	13.66	12.29
	HMH	54.07	7.05	47.01	5.53	10.94	15.51	13.97
	HLH	56.04	7.63	48.42	6.67	3.94	16.95	16.40
	MHH	53.49	4.47	49.02	4.61	21.34	13.87	6.69
	MMH	51.61	4.83	46.78	5.16	13.82	20.82	8.59
	MLH	53.90	5.04	48.87	7.90	5.80	22.16	10.25
	LHH	34.16	3.49	30.67	7.81	25.98	22.55	9.50
	LMH	36.60	2.77	33.83	6.18	18.29	27.97	10.97
	LLH	37.67	2.92	34.75	6.84	15.89	27.75	11.85
	HHM	55.70	6.17	49.53	4.94	18.80	4.93	15.62
	HMM	54.81	6.14	48.67	4.92	11.97	6.66	21.64
	HLM	44.60	4.17	40.44	4.37	4.85	10.47	35.72
	MHM	53.56	4.47	49.09	5.14	24.55	8.19	8.58
	MMM	53.96	4.68	49.28	5.55	15.49	12.69	12.32
	MLM	54.45	6.21	48.24	8.08	6.68	14.99	15.81
	LHM	36.40	2.72	33.68	14.65	25.40	11.68	11.88
	LMM	40.04	2.83	37.21	9.62	15.68	18.26	16.41
	LLM	40.40	3.63	36.77	9.83	10.26	21.15	18.36
PKCa	HHH	47.82	4.52	43.30	7.79	21.04	15.43	7.92
	HMH	46.92	3.80	43.12	8.35	14.90	20.57	9.27
	HLH	50.47	6.03	44.43	11.23	7.45	20.17	10.68
	MHH	46.56	4.79	41.77	6.87	21.22	16.12	9.24
	MMH	47.69	4.30	43.40	5.45	14.02	20.69	12.15
	MLH	50.27	5.05	45.22	6.78	7.62	21.79	13.54
	LHH	45.74	4.95	40.79	2.70	21.70	18.53	11.33
	LMH	47.67	6.56	41.11	3.06	14.12	23.03	12.12
	LLH	46.88	4.50	42.38	3.40	10.57	24.88	14.28
	HHM	45.66	4.17	41.49	14.07	21.44	7.79	11.05
	HMM	48.85	4.47	44.37	10.30	14.06	11.31	15.50
	HLM	45.02	5.06	39.96	12.30	6.24	14.26	22.20
	MHM	48.47	4.53	43.93	7.38	23.50	8.64	12.02
	MMM	49.39	4.58	44.82	6.67	14.75	12.52	16.67
	MLM	48.22	5.64	42.58	6.81	6.80	15.12	23.05
	LHM	51.53	4.65	46.88	3.29	23.81	8.37	13.01
	LMM	50.57	4.59	45.97	3.13	14.33	13.78	18.20
	LLM	46.21	3.30	42.91	3.18	8.75	17.22	24.64

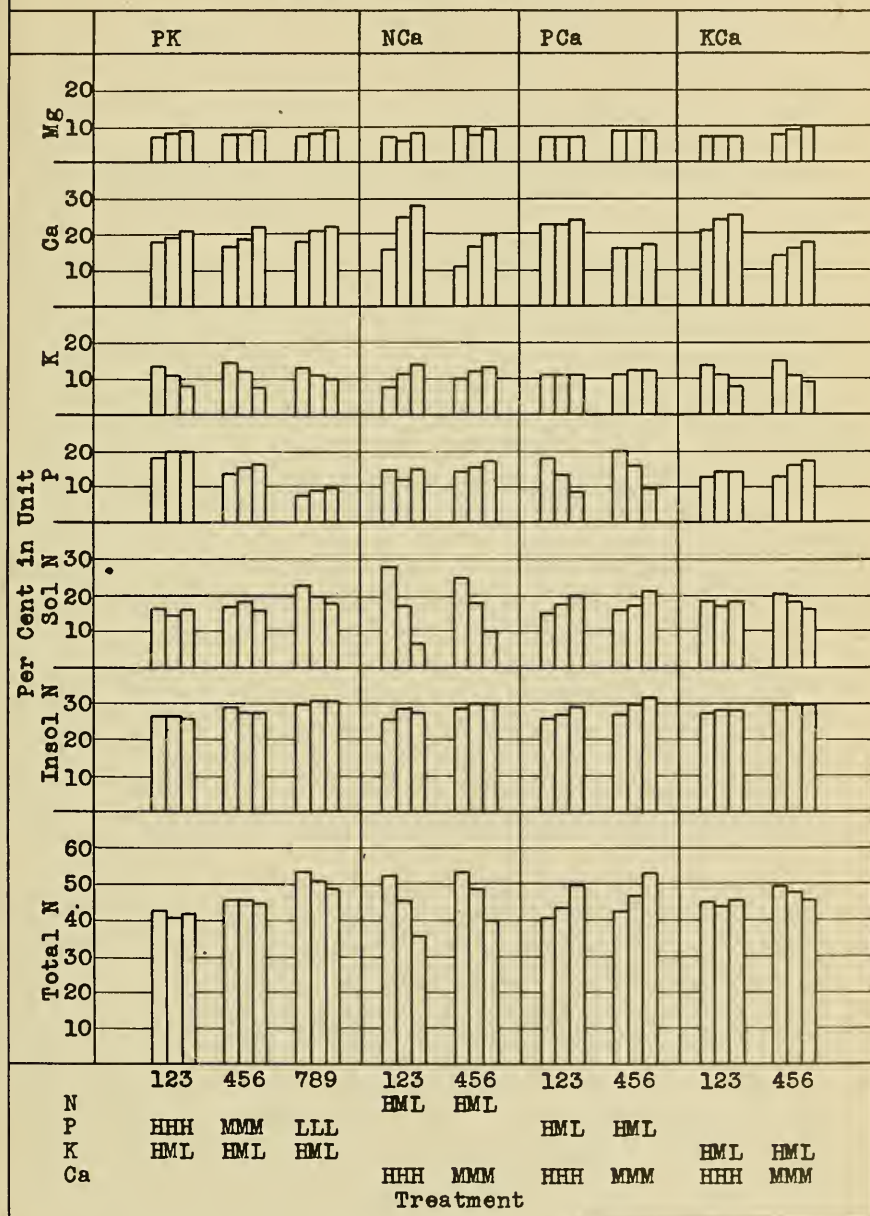
Graph 3b. The N, P, K, Ca and Mg in the Equivalents Units in the Shoots. Averages for Primary Treatments and their Interactions



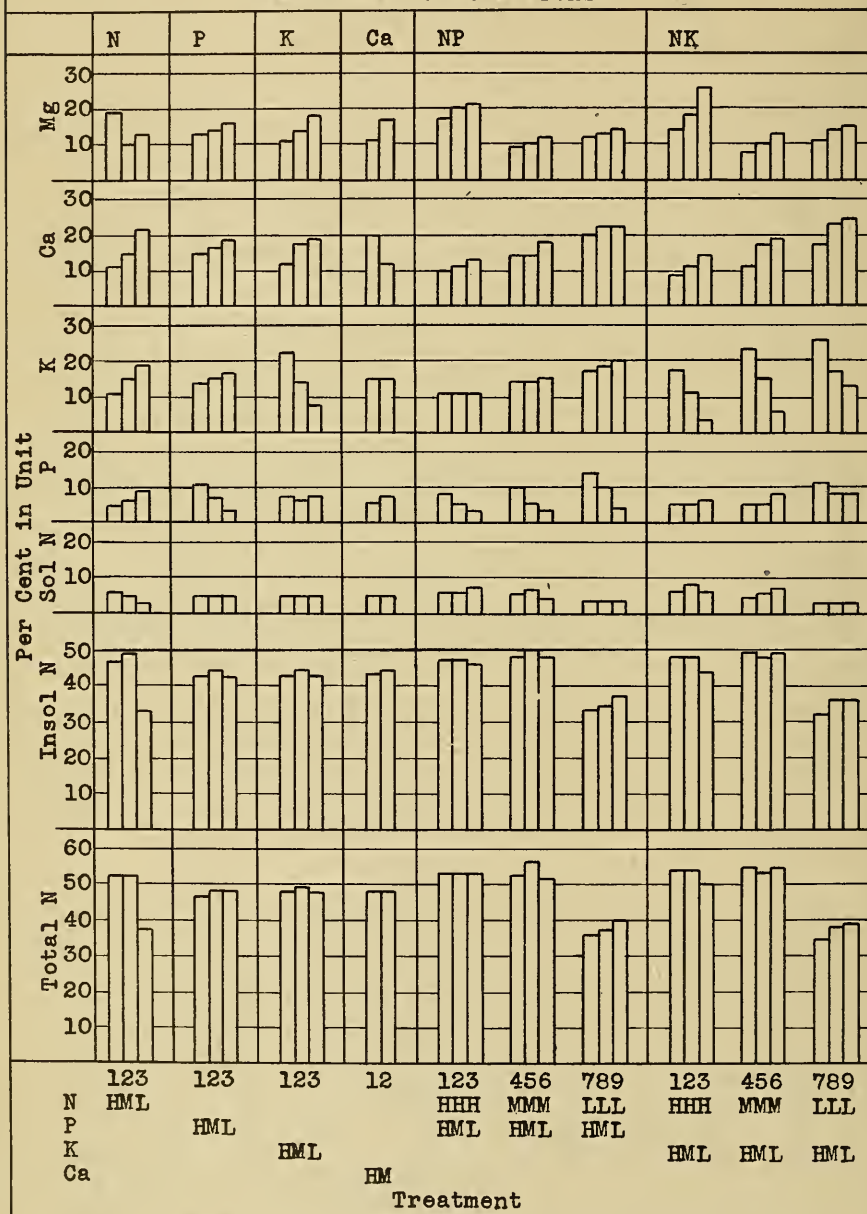
Graph 4a. The N, P, K, Ca and Mg in the Equivalents Units in the Trunks. Averages for Primary Treatments and their Interactions



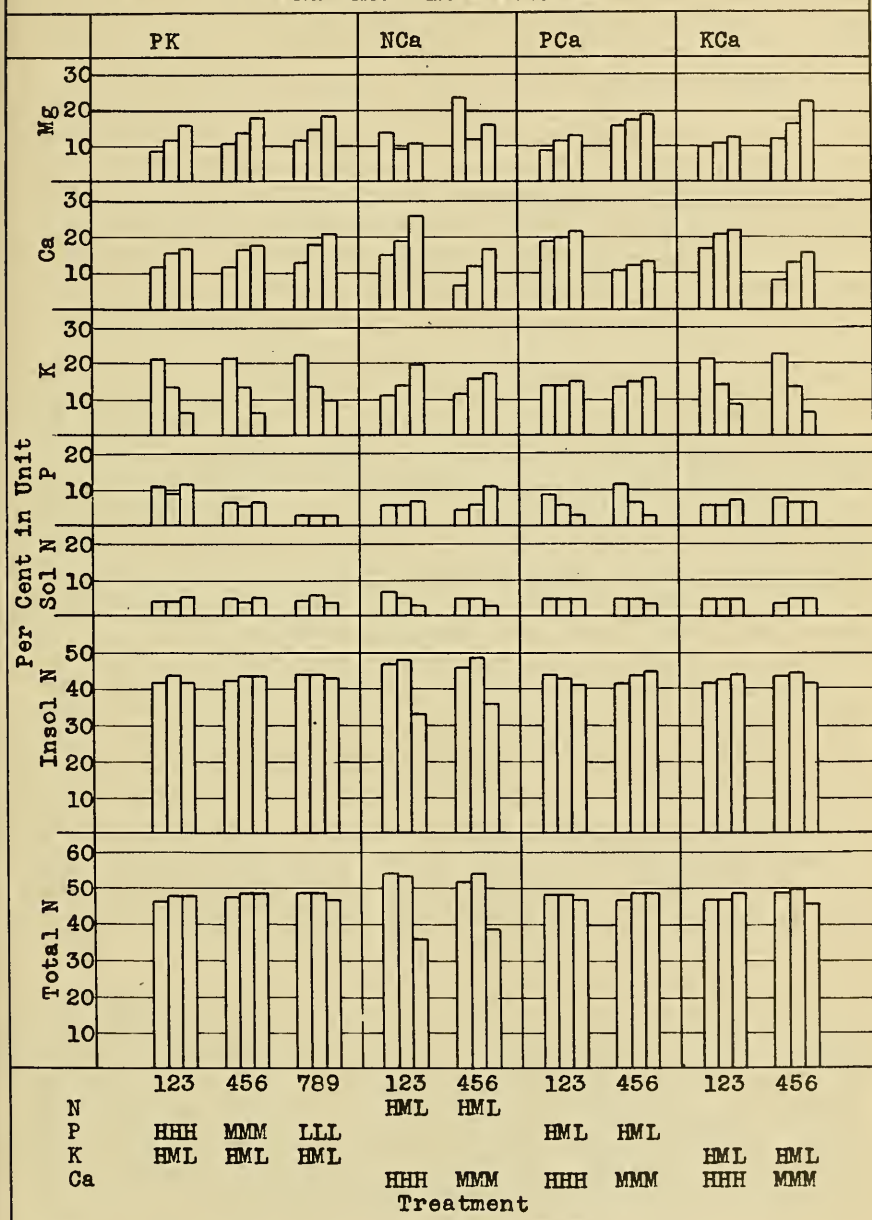
Graph 4b. The N, P, K, Ca and Mg in the Equivalents Units in the Trunks. Averages for Primary Treatments and their Interactions



Graph 5a. The N, P, K, Ca and Mg in the Equivalents Units in the Leaves. Averages for Primary Treatments and their Interactions



Graph 5b. The N, P, K, Ca and Mg in the Equivalents Units in the Leaves. Averages for Primary Treatments and their Interactions



P in the leaves was also lower than it was in the shoots and trunks; the amount of P in the trunks was slightly higher than in the shoots. Both K and Mg were higher in the leaves. With respect to the amount of Ca, differences between the parts of the trees were dependent in part on the supplies of the elements. Thus Ca was usually higher in the trunks than in the leaves and shoots when the supply of Ca was medium, but greater in the shoots than in the trunks and leaves when Ca was high (Tables 3 to 5, Ca). Also, it usually was greatest in the trunks and least in the shoots when the N supply was high, greatest in the trunks and least in the leaves when N was medium, and greatest in the shoots and least in the leaves when N was low (Tables 3 to 5, N).

The Relations between Elements

The fundamental nature of the relations between the elements is indicated by the effects of an increase in the N supply on the composition of the shoots. As the supply of N increased, the amounts of both K and Ca in the equivalent units for the shoots decreased (Graph 3, N). The P, on the other hand, did not always decrease (Graph 3, N). In fact, when the P supply was high, the amount of P in the shoots tended to increase as the N supply increased (Graph 3, NP, Bars 1:4:7). And when P was medium, it decreased as N increased from low to medium but increased when N was raised from medium to high (Graph 3, NP, bars 2:5:8). When P was low, however, it decreased regularly with increasing N (Graph 3, NP, bars 3:6:9). In addition, when Ca was high, the P in the units tended to increase as N increased, whereas when Ca was medium, it decreased (Graph 3, NCa). The Mg in the shoots decreased only with the increase in the N supply from low to medium; the larger Mg supply which accompanied high N naturally resulted in an increased accumulation of Mg in the shoots when N increased to the high level (Graph 3, N).

The fact that an increase in the supply of N tended to decrease the amounts of P, K, Ca, and Mg suggests that fundamentally N was antagonistic to their accumulation in the shoots. This antagonism or repressive effect of N for K, Ca, and Mg was clearly indicated. Even for P, an inverse relation between its accumulation in the shoots and the supply of N was sufficiently evident under some conditions to indicate the fundamental nature of the repressive tendency.

On the other hand, the fact that the repressive effect of N on the bases was expressed more regularly or frequently than its effect on P suggests that there was a difference in the effectiveness or strength of the repressive action of N on different elements. Since it was evident more regularly, the repressive effect of N on the bases was apparently stronger than its effect on P.

The fundamental antagonism which was characteristic of the effects of N was also characteristic for the other elements. It was indicated by the effects of variations in their supply on the composition of the trunks and leaves as well as of the shoots (Graphs 3 to 5, Tables 3 to 5). However, as with N, there were variations in the apparent strength of their repressive effects. These variations for the different elements were evaluated on the basis that the more regularly or frequently an inverse relation was evident between the supply of one element and the amount in the tops of a second, the stronger was the repressive action of the first on the second. A summary of this evaluation, which was made from an examination of Tables 3 to 5, NPCa, NKCa, and PKCa, follows.

An inverse relation was evident with marked frequency for the following comparisons:

- between the amount of N in the tops
and the P supply,
- between the K, Ca, and Mg in the tops
and the N supply, and
- between the N, P, K, and Mg in the tops
and the Ca supply.

Consequently, the repressive action of the following is considered to have been comparatively strong:

- the effect of P on N,
- the effect of N on the bases, K, Ca, and Mg,
- and the effect of Ca on N, P, K, and Mg.

In contrast to the above, the effect of N on P evidently was only moderately strong. The inverse relation between the amount of P in the units for the tops and the N supply was evident frequently only under the conditions of medium Ca (Tables 3 to 5, NPCa, HHM:MYM:LIM, HMM:MMM:LMM, HLM:MLM:LLM). Since it was not as evident, the repressive action of N on P apparently was comparatively weaker than the reciprocal effect of P on N, as noted above.

Also in marked contrast to its action on N, the effect of P on each of the bases was weak. This weakness is indicated by the fact that the K, Ca, and Mg in the tops decreased with the increase in the P supply only in a comparatively few instances (Tables 3 to 5, NPCa, PKCa).

The repressive action of K on N and on P was also weak (Tables 3 to 5, NKCa, PKCa). On the other hand, the effect of K on Ca and on Mg was comparatively strong (Tables 3 to 5, NKCa, PKCa).

It will be noted that, for any two elements, the repressive action of one on a second usually was stronger than the reciprocal effects of the second on the first. Thus, comparatively,

- the repressive effect of P on N was stronger
than that of N on P,
- the repressive effect of N on the bases was
stronger than that of the bases on N,
- the repressive effect of Ca on P was stronger
than that of P on Ca, and
- the repressive effect of Ca on K was stronger
than that of K on Ca.

On the other hand, the repressive actions of P on K and of K on P were both comparatively weak, and there was no indication that either was dominant consistently.

Fundamentally, for any element the evaluation of the relative strength of its repressive action is an indication of the degree to which the expression of its normal antagonism was influenced or modified by the effects of other elements. Thus evidence of comparative weakness in the effects of an element indicates that the expression of its antagonism was dependent on and easily influenced by the concurrent effects of the other elements. Similarly, evidence of comparatively strong action indicates that the effects of other elements were generally at a minimum or easily offset; on the other hand, for such an element the occasional exceptions to an inverse relation between the supply of that element and the amount of a second in the tops represent the particular situations in which its repressive effects were modified or reduced by the concurrent actions of other elements.

The modifying effect of the elements on the expression

of the repressive action of one of their number can be illustrated by consideration of the effects of an increasing N supply on the accumulation of P in the shoots (Table 3, NPCa). Under the conditions of medium Ca, the repressive effect of N on P evidently was strong enough to overcome any of the concurrent effects of other elements which might have markedly modified an expression of that antagonism. As a result the P in the equivalents units for the shoots decreased regularly as the N supply increased (Table 3, NPCa, LHM:MHM:HHM, LMM:MMM:HMM, LLM:MLM:HLM).

Under the conditions of high Ca, however, the results were different, the reaction to N varying with the P supply. Thus the amount of P in the units decreased regularly as the N supply increased only when the supply of P was low (Table 3, NPCa, LLH:MLH:HLH). At the medium P level it decreased when N increased from low to medium but increased when N was raised to the high level (Table 3, NPCa, LMH:MMH:HHM). At high P it increased regularly as N increased (Table 3, NPCa, LHH:MHH:HHH).

Under these various conditions, Ca was a dominant element because of its high supply. It strongly depressed both N and P. At low-P-high-Ca the repression of P by Ca was at a maximum, since any reciprocal effect of P on Ca was minimized by the low P supply. Likewise the usually strong repressive action of P on N was at a minimum, whereas that of N on P was comparatively greater, with the result that the P in the shoots decreased as the N supply increased, the depressing effects of N on P being added to those of the high Ca. It will be noted, however that the effectiveness of N on P was reduced by the high Ca; comparatively, the decrease in P at low-P-medium-Ca was greater than that at low-P-high-Ca (Table 3, NPCa, LLM:MLM:HLM, LLH:MLH:HLH).

At medium-P-high-Ca, the repression of P by Ca was still comparatively great, though somewhat less than at low-P-high-Ca, because the reciprocal effect of P on Ca naturally was stronger at the medium P level. However, the net effectiveness of P on both Ca and N was not sufficient to offset the effect of the increase in N from low to medium, so that, as a result, the P in the shoots was lower at medium-N-medium-P-high-Ca than at low-N-medium-P-high-Ca. On the other hand, when N increased to the high level, the net result of the interactions of the elements was altered so that the P in the shoots increased. This effect was probably as much

the result of the higher Mg supply accompanying high N as it was of the increase in N itself. Because of its antagonism to Ca, the higher Mg reduced the effect of the high Ca on P and N. In addition, the high N itself was antagonistic to Ca, and its effects were probably added to those of Mg. Apparently the mutual antagonism of N, Ca, and Mg was such that their action, both individually and collectively, on P was minimized, with the result that conditions for the accumulation of P were more favorable at high-N-medium-P-high-Ca than at medium-N-medium-P-high-Ca.

Under conditions of high-P-high-Ca, the high level of P itself was obviously favorable to a comparatively large accumulation of P in the shoots. In addition, the fundamental antagonism of P for both N and Ca was greater than at lower levels of P; therefore, to begin with, the reciprocal effects of N on P and of Ca on P were comparatively minimized because of the high P. At the same time, however, the mutual antagonism of N and Ca also reduced the repressive effect of each of those elements on P. In particular, as the N supply increased, the increased repression of Ca was favorable to the accumulation of P. Therefore under conditions of high-P-high-Ca the P in the shoots actually increased as the N supply increased, an effect which was the end result of the interaction of several factors, especially the fundamentally favorable P supply and the antagonism of N and Ca (together with Mg at high N).

In addition to being modified by the effects of other elements, the expression of the normal antagonism of an element also varied in some instances in the different parts of the trees, so that the strength of the repressive action sometimes appeared to be greater in one part than in another. Apparently the variation in the natural level of accumulation of the elements was sometimes great enough between parts of the trees to modify the expression of the antagonism. This sort of variation is illustrated by the effects of P on the accumulation of N in the shoots and trunks as compared with that in the leaves. In both the shoots and trunks, the repressive effect of P on N was strong, the amount of N in those parts decreasing regularly as the P supply increased (Tables 3 and 4, NPCa). In the leaves, however, the effect was comparatively weaker, and under some conditions the N actually increased as the P supply increased (e.g., Table 5, NPCa, MLM:MMM).

The comparative weakness of the effect of P in the leaves evidently was related to a naturally lower level of accumulation of that element and a higher accumulation of the bases, especially K and Mg. The lower level of accumulation of P weakened the effectiveness of the antagonism of P for N. In addition, the potential repressive effect of the bases on N was greater as a consequence of their higher accumulation. However, because the increase of K and Mg in the leaves was greater than that of Ca, the intensity of the mutual antagonism between the bases apparently was increased with a resultant decrease in their effectiveness on N and P. Consequently, the reciprocal effect of P on the bases was relatively strengthened so that an increase in the P supply resulted in a decrease in one or more of the bases which further reduced the intensity of the repression of N by those bases. The end result of the interaction of these factors therefore was a comparatively weak expression of the repressive effect of P on N; evidently the favorable effect on N of the decrease in the bases which resulted with the increase in the supply of P outweighed the unfavorable, direct effect of P on N. Consequently, under some conditions the N in the leaves actually increased as the P supply increased. Even for the conditions under which N decreased, the intensity of the repressive effect of P on N was comparatively less than in the shoots and trunks.

III. THE RELATION BETWEEN GROWTH AND COMPOSITION

It is evident from the discussion of the analytical data that at least three factors were operative in determining the composition of the tops of the trees: first, the nature of the part of the tree; second, the supply of the elements individually; and third, the normal antagonism between them. In effect, the first two limited the accumulation of an element within a given portion of a tree. The third, however, accounted for its variations within those limits, so that consequently, the composition of the tops was always dependent in the end on the relationships between the elements supplied to the tree.

Under the discussion of growth it was pointed out that the growth of the shoots also was dependent on the relationships between the elements or on the intensity of the nutrient-element balance. Obviously, therefore, a relation between the composition, growth, and balance is to be expected. The following discussion is concerned with the nature of that relationship.

The Relations at High N: In previous discussion it was concluded on the basis of the growth data alone that the reduced shoot growth in the high N series was the result of excessive N and a consequent lowered intensity of balance in the nutrient-element supply. The effect of the high N on the composition of the shoots in its relation to growth will now be considered. As expressed in the composition, the excess N resulted in a decreased accumulation of both K and Ca. Mg, however, increased because of the higher supply of Mg accompanying high N. The P in the shoots was affected by the Ca supply as well as by N, so that it was higher at high-N-high-Ca than at medium-N-high-Ca but lower at high-N-medium-Ca than at medium-N-medium-Ca. The total N in the shoots increased. However, this increase was entirely as soluble N, since the insoluble portion decreased (Table 3, NPCa, NKCa).

It is the accumulation of the soluble relative to the insoluble N which apparently was a primary factor in the reduced growth at high N. Evidently the alterations noted above in the accumulations of the other elements produced conditions which were less favorable for an adequate synthesis of insoluble (protein) N. These conditions were brought about in the main by the high N supply itself as a

result of an increase in the intensity of the antagonism of N for the other elements, especially the bases. In addition, the repressive effect of Mg was intensified at high N because of the accompanying high Mg supply.

The higher Mg, however, was only secondary to N in the degree to which it influenced the composition and growth of the shoots in the high N trees. This fact becomes apparent when the trees which received high-N-high-Ca are compared with those at medium-N-medium-Ca (Tables 2 and 3, NCa). Best growth resulted under the latter conditions. The difference in the nutrient-element supply for these two groups of trees involved N, Ca, and Mg, all three being higher in the high-N-high-Ca solutions. Nevertheless, only N was present in an increased amount within the shoots of the trees receiving those solutions; the increase, however, was entirely as soluble N, the insoluble portion decreasing. This increase of the soluble relative to the insoluble N being indicative of an inefficient synthesis of protein N accounts for the reduced growth of those shoots.

The unfavorable relation of the soluble to the insoluble N was not, however, a direct consequence of the higher Mg supply accompanying the high N, as is indicated by the fact that there was practically no difference in either the Mg or Ca in the shoots at high-N-high-Ca as compared to those at medium-N-medium-Ca. Evidently, the mutual antagonism of Mg and Ca was such that, when the supplies of both were increased, there was little change in their relative accumulation within the shoots. The K in the shoots, on the other hand, decreased. It is likely that it was this decrease in K with its consequent effect on the relation of K to Ca and Mg which resulted in the unfavorable soluble-insoluble-N relation. The decrease in K was evidently the result primarily of the repressive effect of the high N, since the mutual antagonism of Mg and Ca would have reduced their individual repressive effect on K. Therefore, the lower intensity of balance in the high-N-high-Ca solutions was primarily the result of the higher N supply. Because the effectiveness of N in the other high N series was potentially the same, it can be concluded that the lower intensity of balance of those solutions also was a consequence of the high N. If anything, the accompanying high Mg supply merely intensified the effects of N and caused wider variations in the relative amounts of the bases in the shoots than might otherwise have resulted.

The Relations in the Deficiency Series: The reduced growth of the trees in the low-N series is indicative of a low intensity of nutrient-element balance and presumably was the direct effect of the low-N supply. The nature of that effect is shown by a comparison of the composition of the shoots of trees at low and at medium N (Table 3, N). In the first place, the total N in the shoots was greatly reduced at low N. This reduction was accounted for primarily by a decrease in the soluble N. The concurrent decrease in the insoluble N, though relatively smaller, indicates that the synthesis of insoluble (protein) N was inadequate for best growth. Evidently the supply of N was insufficient to maintain a level of soluble N in the shoots which was favorable to a continued and rapid synthesis of the insoluble forms. In addition to the difference in the N in the shoots, the accumulations of the other elements were usually higher at low than at medium N. Such increased accumulations were a natural consequence of a decrease in the intensity of the normal antagonism of N under the conditions of a low N supply.

The low intensity of balance indicated by the reduced growth when the supply of P was low was a consequence of the effects of the deficiency of that element. The nature of those effects is indicated by the composition of the shoots. The amount of P in the shoots of the low P trees was characteristically low (Table 3, P). In addition, in contrast to the medium P trees, there was an accumulation of soluble relative to insoluble N, which indicates that conditions were unfavorable for a satisfactory synthesis of protein N. Evidently, the amount of P in the shoots was insufficient to favor that synthesis. Besides any direct effects of the low P on protein synthesis, the concurrent lowered intensity of its normal antagonism naturally resulted in a greater accumulation of N. The amounts of the bases in the shoots were not greatly different than at medium P. On the other hand, however, if they are compared to the amounts of P in the shoots, the bases actually were relatively greater at low than at medium P. This condition probably intensified the unfavorable effects of the low P supply.

The low intensity of balance indicated by the reduced growth under conditions of low K was a consequence of the effects of the deficiency of that element. The nature of those effects as indicated by the composition of the shoots (Table 3, K) was very similar to that of low P in that an accumulation of soluble relative to insoluble N was also characteristic. Evidently, the low amount of K in the shoots

under the conditions of the deficiency was unfavorable to the synthesis of the insoluble forms of N. The effects of the low K also were probably intensified by the relatively greater accumulations of the other bases and of P.

The Mild Deficiency of K: As presented in the discussion of growth, the intensity of nutrient-element balance under conditions of medium-K-medium-Ca was shown to be lower than under high-K-medium-Ca. The lower growth under the former conditions was considered to be, in part at least, the result of a mild deficiency of K. The nature of the effects of that deficiency is indicated by a comparison of the composition of the shoots under the two sets of conditions (Table 3, KCa).

At medium-K-medium-Ca, the K in the shoots was lower than at high-K-medium-Ca. The Ca and Mg in the shoots, however, were both higher, because the intensity of the repressive effect of K was naturally lower with medium K. The ratio of K to Ca and Mg consequently was markedly lower than at high-K-medium-Ca. It was this narrower interbase relationship which apparently conditioned the lower growth at medium-K-medium-Ca. However, it appears to have been a factor through its effect on the soluble-insoluble-N relation in the shoots. The insoluble N was lower and the soluble N was higher under the conditions of medium-K-medium-Ca. The greater amount of soluble relative to insoluble N evidently was less favorable to growth than that at high-K-medium-Ca.

Under the conditions of high Ca, medium K was not mildly deficient. In fact, the intensity of balance with medium-K-high-Ca was in general higher than with high-K-high-Ca, and growth tended to be better under the former conditions. Apparently, under the conditions of high Ca, the increase in K to the high level did not result in an interbase relationship which was more favorable to growth, even though it did reduce both the Ca and Mg in the shoots. In fact, by its antagonism to Ca it apparently reduced the repressive effect of that element on N so that the soluble N in particular was higher at high-K-high-Ca than at medium-K-high-Ca. At the same time, the conditions for the synthesis of the insoluble forms of N evidently were not improved, with the result that the soluble N was relatively higher than the insoluble forms. Consequently growth at high-K-high-Ca tended to be lower than at medium-K-high-Ca.

The Mild Deficiency of Ca: The intensity of the nutrient-element balance under the conditions of medium-K-medium-Ca was also lower than under medium-K-high-Ca. The smaller growth under the former conditions therefore may just as well be considered as partly the result of a mild deficiency of Ca as the result of the mild deficiency of K discussed above. The nature of the effects of Ca is indicated by a comparison of the composition of the shoots under the two sets of conditions, medium-K-medium-Ca and medium-K-high-Ca (Table 3, KCa).

Under the first set of conditions, the Ca in the shoots was much lower than at medium-K-high-Ca. Both the Mg and the K in the shoots were higher, the Mg being especially so. Consequently the ratio of Ca to K and Mg was markedly lower than at medium-K-high-Ca. It was this narrower interbase relationship which apparently conditioned the lower growth at medium-K-medium-Ca. However, it appears to have been a factor through its effect on the soluble-insoluble-N relation in the shoots. Both the soluble and the insoluble N were higher under the conditions of medium-K-medium-Ca. However, the difference in the soluble N was comparatively the greater, so that the soluble portion was actually higher relative to the insoluble N under those conditions and was less favorable to growth than at medium-K-high-Ca.

Under the conditions of high K, the medium Ca was not mildly deficient. In fact, the intensity of balance with high-K-medium-Ca was in general higher than with high-K-high-Ca, and growth tended to be better under the former conditions. The increase in Ca, under the conditions of high K, resulted in a decrease in the total N in the shoots, because of the strong repressive effect of the high Ca. This decrease was accounted for by reduction in both the soluble and the insoluble N. However, the decrease in the soluble forms was the smaller. Actually therefore there was an increase in the soluble relative to the insoluble N, a condition which was less favorable to growth. This soluble-insoluble-N relation was conditioned by the effect of the high Ca on the other bases. Both the K and the Mg in the shoots were lower at high-K-high-Ca than at high-K-medium-Ca as a result of the repressive effect of the higher Ca. However, this reduction in K and Mg naturally lowered the intensity of their repressive effect on the N within the shoots, so that conditions were favorable for an increase in the soluble relative to the insoluble N.

The Effect of Ca at low K: When either the medium or high N was accompanied by low K, an increase in Ca resulted in an increased growth. Under the conditions of high-N-low-K, this increase in Ca was favorable to growth because it reduced sharply the Mg accumulation in the shoots (Table 3, NKCa). If the high Mg supply accompanying high N had any direct "toxic" effect on growth it would have been most serious under the conditions of low-K-medium-Ca, because the intensity of the repressive effects of both K and Ca on Mg was at a minimum under those conditions. Consequently, when the Ca supply was increased and the intensity of its antagonism for Mg was heightened, the effect of Mg was reduced, and growth improved.

That this improvement in growth was a direct result of the shift in the Ca-Mg relation in the shoots rather than a consequence of concurrent alterations in the nitrogen economy is indicated by comparison of the nitrogen data under the conditions of high-N-low-K-medium-Ca and high-N-low-K-high-Ca (Table 3, NKCa). The total N increased as the Ca supply increased. This increase was accounted for solely by an increase in the soluble N, the insoluble portion being decreased. Such increase in the soluble relative to the insoluble N was usually unfavorable to growth. In this instance, however, it evidently was of less importance than the shift in the Ca-Mg relation. The situation is especially noteworthy since the increase in the soluble N undoubtedly was a consequence of the increase in Ca; the higher Ca by reducing the accumulation of Mg in the shoots lowered the intensity of the antagonism of that element for N with the result that the N increased. The increase in the Ca supply under conditions of high-N-low-K was favorable to growth despite the fact that it resulted in a normally unfavorable nitrogen relationship.

Under the conditions of medium-N-low-K, in contrast to the situation at high N, the increase in Ca was favorable to growth because of its effect on the soluble-insoluble-N relation (Table 3, NKCa). The increase in Ca under those conditions resulted in a decrease in total N. This decrease was accounted for primarily by a decrease in the soluble fraction and resulted in a lower accumulation of soluble relative to insoluble N, a condition which was more favorable to growth. The decrease in the soluble N was probably a direct result of the antagonism of Ca for that element. The concurrent

decrease in the accumulations of K, Mg, and P in the shoots evidently was also favorable; presumably their relationship to N was more satisfactory.

The beneficial effect of an increase in Ca discussed above is also of especial interest because such a result is contrary to the effects of Ca as reported by Davidson and Blake (8) and by Shaw (13, 14). The former, working with peach trees in sand cultures, reported that the trees receiving solutions containing 2 ppm of K made more growth when the accompanying supply of Ca was at a concentration of 180 ppm than when it was 410 ppm. Shaw found that fruit plants grew better where both lime and potash had been used than where potash alone had been applied; on the other hand, where potash had not been used, growth was better on an unlimed plot. In other words, where K was deficient, Ca additions were detrimental, but when the K deficiency was corrected, Ca became limiting, and growth was improved by liming.

Because the data presented by those investigators is insufficient to make possible an evaluation of the nature of the effects of Ca under their conditions, the difference between their results and those of this investigation cannot be accounted for precisely. Presumably, however, it is a result of differences in the absolute and relative supplies of other elements in addition to K and Ca. With such different supplies, the relations between the bases and between the forms of nitrogen within the plants might easily have varied sufficiently to produce the different growth responses.

It will be noted, however, that the improvement in growth with liming after the deficiency of K was corrected as reported by Shaw was similar to the effect of an increase in Ca under the conditions of medium K in this investigation. This indicates that fundamentally the effects of the relations between K and Ca in the two investigations were actually similar. Presumably, therefore, the effects were also fundamentally similar under the conditions of K deficiency but were expressed differently because of variations in other conditioning factors. It seems likely that the divergent results could be readily reconciled if sufficient information, especially as to analytical data, were available to evaluate the effects of those other factors.

The Effects of P: In the discussion of growth it was pointed out that the increase in the supply of P from medium

to high had no significant effect on the growth of the shoots. Consequently, in so far as growth was concerned, the intensity of nutrient-element balance under the conditions of high P was practically the same as that under medium P. On the other hand, the composition of the shoots differed under the two conditions (Table 3, P). In the first place, the increase in the supply of P to the high level resulted in a definite increase in the P in the shoots. In addition, the N in the shoots decreased as a result of the strong antagonism of P. The K, Ca, and Mg, however, were not markedly affected, since P was only weakly repressive of the bases. Most of the decrease in N was accounted for by the soluble forms. As a consequence, as P increased there was usually a decrease in the soluble relative to the insoluble N. Under most conditions, such a shift in the soluble-insoluble-N relation would have resulted in increased growth; however, as previously mentioned, that did not occur to any marked degree with the increase in the P supply to the high level.

This result appears to have been a consequence of the difference in the antagonism of P on N and on the bases. This difference was such that, with the increase in the P supply, there was very little decrease in the bases as compared with a marked decrease in N. Consequently most of the increase in the P in the shoots usually was accounted for by a corresponding decrease in N, the soluble portion especially. As a result, the sum of P and the soluble N was approximately the same under conditions of the medium and high P supplies. Therefore the relation of the P-plus-soluble-N to the insoluble N was also nearly the same. This suggests that, under conditions of high P supply, the additional P in the shoots substituted, at least partly, for soluble N to maintain with insoluble N a relationship which was no more favorable to growth than that under conditions of medium P supply.

In so far as the composition of the shoots is a criterion, the increase in the P supply can be considered to have caused changes in the quality of growth, even though it did not result in differences in the amount of growth. Thus the decrease in the total N and the shift in the soluble-insoluble-N relation with the increasing P supply represent a change in the quality of growth from the standpoint of the nitrogen economy. Likewise, the increase in the P in the shoots relative to N and to the bases constitutes a difference in quality. Therefore, in so far as the composition of the shoots was concerned, the intensity of the nutrient-element balance can be considered to have varied with the in-

creased P supply, despite the fact that it was no different on the basis of growth.

The significance of the quality factor in nutrient-element balance, however, depends on the purpose for which the plants are grown. When the volume or amount of growth produced is of primary importance, quality may be of little direct significance, and balance may be defined solely on the basis of growth. On the other hand, when other functions of the plant are concerned, such as fruiting, the quality of growth may also have to be considered and balance defined or qualified in terms of the composition as well as the amount of growth. Since this investigation is concerned principally with the amount of growth, the implications of the quality factor can only be indicated. It should not be construed that the effect of the P supply on the quality of growth is necessarily significant from the standpoint of other developmental phases of peach trees. The effects of P have been used merely to illustrate the points that variations in the nutrient-element supply may cause differences in the composition of the plants without significant, concurrent changes in the amount of growth and that, under some conditions and for some purposes, balance may need to be defined in terms of the quality as well as the amount of growth.

The Diagnosis of Deficiencies

There were two features of the trees under the acute deficiency conditions of either low N, low P, or low K which were diagnostic. The first was the symptoms which characterized the foliage and shoot growth for each of the respective deficiencies. The second was the typically low level of accumulation of the deficient element in the tops of the trees. Both of these features have a practical value in diagnosing the deficiencies. The symptoms have frequently been described and used (4, 7, 8, 20). The analyses of leaves have been found valuable in the diagnosis of K deficiency especially (3, 18, 19).

However, these features were not diagnostic of the milder deficiencies such as the deficiency of K under the conditions of medium-K-medium-Ca. In that particular instance there were no special symptoms, only the smaller growth as compared with the trees at high-K-medium-Ca. In addition, the analyses for K did not indicate the deficiency; in fact

the K in the shoots as expressed in the equivalents units was higher at medium-K-medium-Ca than at medium-K-high-Ca, under which conditions K was not mildly deficient.

The diagnosis of the mild deficiency was made, however, by reference to the tree making maximum growth. For example, maximum growth resulted under conditions of medium-N-high-K-medium-Ca. In comparison, growth was smaller under conditions of medium-N-medium-K-medium-Ca. Therefore the smaller growth must have been a consequence of a mild deficiency of K, since it was improved by increasing the supply of that element. Obviously a standard of reference, representing maximum growth, is needed in diagnosing a mild deficiency. In addition, the available supplies of the various elements must be known. The deficiency can then be diagnosed by considering the difference in the nutrient-element supplies which can be related to the difference in growth between the standard or reference trees and those making comparatively poorer growth.

A standard of reference is also needed if the plant analyses are to be of value in diagnosing the deficiency. For example, using again the trees at medium-N-high-K-medium-Ca as a standard, the greater amount of soluble relative to insoluble N in the shoots of the trees making smaller growth under the conditions of medium-N-medium-K-medium-Ca was indicative of a mild deficiency that was influencing the quality of nitrogen. The comparatively lower K, together with the concurrently higher Ca and Mg, in the shoots at medium-N-medium-K-medium-Ca indicates that K was the deficient element and that better growth under the reference conditions was the consequence of a more favorable interbase relationship which resulted in improvement in the quality of N.

It is to be expected that analyses of the tissues would be of most help in diagnosing a mild deficiency, when the differences in the nutrient-element supplies which were available to the deficient and the reference plants respectively involved more than one element. Under such conditions it might be difficult to assign differences in growth to one of the variable elements in particular, unless comparisons of the inter-elemental relationships within the plants could also be made and used to aid in indicating the element most likely to be limiting.

SUMMARY

1. Elberta peach trees were grown in sand culture, using 54 different treatments which included all of the possible combinations of supplies of N, P, and K at three concentrations--high, medium, and low--and of Ca at two--high and medium. The low concentrations were selected as "deficiency" levels, such concentrations being used only for N, P, and K but not for Ca. The medium concentrations were considered adequate for good growth. The high concentrations were selected with the possibility in mind that they might prove to be greatly excessive.

2. The trees were harvested about five months after planting. Growth was measured in terms of the length and the dry weight of shoots. Samples of the leaves, shoots, and trunks were analyzed for P, K, Ca, Mg and for water-soluble, water-insoluble, and total N. The amounts of these elements in the samples were expressed in terms of an equivalents unit; i.e., as the percentage of each in the sum of their microgram-hydrogen-equivalents per gram of dry weight.

3. Nutrient-element balance was defined and qualified in terms of the factors limiting growth. Such a procedure provided for a number of balanced nutrient-element supplies which were distinguished by the differences in their intensity of balance as determined by the amount of growth produced. The nutrient-element supply with the highest intensity of balance was defined as that one with which resulted the maximum amount of growth possible within the limits of other environmental factors and of the genetic nature of the plant. As any element became limiting, a balanced supply of a comparatively lower intensity was defined as that one which resulted in the maximum growth possible within the limits of the supply of that element.

4. Nitrogen was the most important of the elements as a determinant of growth. Considering the experiment as a whole, maximum growth occurred when the N supply was medium regardless of the supplies of the other elements. Growth at low N was greatly reduced; that at high N was intermediate. The supplies with the highest intensities of balance included N at the medium level.

5. K and Ca were closely related and next to N in importance in their effects on growth. Within the limits of either the high or the medium N supply, there were two com-

binations of K and Ca which were nearly equal with respect to growth. They were high-K-medium-Ca and medium-K-high-Ca. Within the limits of the N supply, the solutions with the highest intensities of balance included K and Ca in one or the other of those two combinations. Growth at low K was less than at medium or high K.

6. P was the least important of the four elements as a determinant of growth. There was no significant difference in growth under the medium and the high P conditions. Therefore the intensities of balance of supplies including high P were practically the same as those with the medium level of that element. Growth at low P, however, was greatly reduced.

7. Acute deficiencies resulted under the conditions of a low supply of N, P, or K. They were characterized by markedly reduced growth and typical deficiency symptoms.

8. Growth was better with high-K-medium-Ca and medium-K-high-Ca than with medium-K-medium-Ca. The comparatively poorer growth under the latter conditions was considered the result of in part a mild deficiency of K and in part a mild deficiency of Ca, since in the one instance growth improved by increasing K and in the other by increasing Ca. The only evidence of the deficiency was the comparatively lower growth; no typical foliage symptoms were evident.

9. Under the conditions of low K, growth improved with an increase in the Ca supply.

10. The amount of an element in the microgram-hydrogen-equivalents units for the tops of the trees was determined primarily by the supply of that element.

11. The leaves, shoots, and trunks differed as to the amounts of the elements within them, probably as a result of natural differences in their structure and functions. Soluble N and P were lower in the leaves than in the shoots and trunks, while insoluble N, K, and Mg were higher. Differences between the parts of the trees with respect to Ca varied with the Ca and the N supplies.

12. Fundamentally, each element was antagonistic, at least potentially, to the accumulation of each of the others within the tops of the trees.

13. The apparent strength of the antagonism or repressive effect of the elements varied. A comparatively strong repressive action was indicated for the following:

the effect of P on N,
the effect of N on K, Ca, and Mg, and
the effect of Ca on N, P, K, and Mg.

The effects of N on P and of K on Ca and Mg were only moderately strong. The effect of P on each of the bases was weak; that of K on P was also weak.

an 14. The relative strength of the repressive effect of an element was an indication of the degree to which an expression of its normal antagonism was influenced or modified by the effects of other elements. A comparatively weak action was ~~an~~ indication that the expression of its antagonism was dependent on and easily influenced by the concurrent effects of other elements. A comparatively strong repressive action indicated that the effects of other elements were generally at a minimum or easily offset.

15. The expression of the normal antagonism of an element also varied in some instances in the different parts of the trees so that the strength of the repressive effect sometimes appeared to be greater in one part than in another. Variation in the natural level of accumulations of the elements was sometimes great enough between parts of the trees to modify the expression of the antagonism.

16. Differences in growth (intensities of nutrient-element balance) were dependent on the relation of the soluble to the insoluble N as affected by the other elements in the shoots. An increase in growth usually resulted when the soluble N decreased relative to the insoluble portion.

17. The reduced growth with the low intensities of balance in the acute deficiency series was related to an inadequate synthesis of insoluble (protein) N.

18. The moderately low intensities of balance under conditions of the mild deficiencies of K and Ca resulted in somewhat reduced growth as a consequence of an unfavorable soluble-insoluble-N relation which was conditioned by a narrower inter-base relationship in the shoots.

19. Under conditions of high^N and low K, the beneficial effect of high Ca was the result of a narrower Ca-Mg relationship without a concurrent favorable shift in the relation of

the soluble to the insoluble N. On the other hand, under conditions of medium N and low K, the beneficial effects of high Ca were the result of a decrease in the soluble relative to the insoluble N, a shift which was conditioned by changes in the inter-base relationship.

20. High P did not alter significantly the intensity of balance resulting with medium P, because apparently at the higher level the P in the shoots partly substituted for soluble N to maintain with the insoluble portion a relation which was no more favorable to growth than the relation at the medium level. However, even though it did not alter the amount of growth appreciably, the high P level caused variations in the quality of growth as indicated by changes in the composition of the shoots.

21. The diagnosis of acute and mild deficiencies was discussed.

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Appendix Table 1. Growth Measurements for Individual Trees. Length and Dry Weight of Shoots and Dry Weight per Millimeter of Length

Treatment NPKCa	Length (millimeters)		Weight (grams)		Weight/Length (mg/mm)	
	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
HHHH	9385	15065	85.4	149.2	9.1	9.9
HHHM	11015	12575	106.2	119.3	9.6	9.5
HHMH	9625	15130	99.8	120.4	10.4	8.0
HHMM	7310	6815	68.8	64.0	9.4	9.4
HHLH	9385	6765	56.8	42.9	6.1	6.3
HHLM	1380	1405	8.8	5.2	6.4	3.7
HMHM	8640	12010	61.5	111.1	7.1	9.3
HMMH	10530	11450	127.8	142.9	12.1	12.5
HMMM	11350	6690	106.1	49.9	9.3	7.5
HMMH	9910	6735	108.1	75.3	10.9	11.2
HMLH	12865	4815	93.7	23.8	7.3	4.9
HMLM	1070	1085	4.3	5.4	4.0	5.0
HLHH	1905	1755	18.3	21.5	9.6	12.3
HLHM	3530	3315	47.6	34.1	13.5	10.3
HLMH	3290	2815	40.0	31.8	12.2	11.3
HLMM	2575	1880	30.7	25.2	11.9	13.4
HLHL	2085	1850	16.5	18.0	7.9	9.7
HLLM	1240	1510	10.0	13.1	8.1	8.7
MHHH	11295	16230	104.9	218.2	9.3	13.4
MHHM	13775	18720	198.2	209.1	14.4	11.2
MHHH	17475	16135	195.4	157.5	11.2	9.8
MHHM	14545	15350	143.9	191.6	9.9	12.5
MHLH	12920	14805	128.1	124.6	9.9	8.4
MHLM	9230	5985	71.9	50.2	7.8	8.4
MMHH	11135	10165	171.0	105.7	15.4	10.4
MMHM	14385	16325	222.7	238.1	15.5	14.6
MMMH	15140	17775	200.5	205.7	13.2	11.6
MMMM	9730	15630	123.8	202.1	12.7	12.9
MMHL	13710	8770	121.0	79.3	8.8	9.0
MMLM	5740	5905	36.1	52.3	6.3	8.8
MLHH	2470	3395	27.7	40.4	11.2	11.9
MLHM	2475	3285	30.5	46.3	12.3	14.1
MLMH	3095	2950	35.1	37.3	11.3	12.6
MLMM	3935	1825	47.1	20.7	12.0	11.3
MLHL	3160	4075	41.1	50.3	13.0	12.3
MLLM	1225	1810	10.4	17.9	8.5	9.9
LHHH	2015	1665	12.7	7.2	6.3	4.3
LHHM	1525	1670	11.0	10.5	7.2	6.3
LEMH	2520	1765	15.7	8.1	6.2	4.6
LEMM	1450	1075	13.4	9.2	9.2	8.6
LHLH	1745	1340	11.2	4.2	6.4	3.1
LHLM	1870	1430	14.4	12.6	7.7	8.8
LMHH	2575	1760	20.9	8.9	8.1	5.1
LMHM	2105	1955	21.5	12.8	10.2	6.5
LMMH	2945	1910	31.2	10.8	10.6	5.7
LMMM	2260	2120	21.1	14.5	9.3	6.8
LMHL	2080	1540	16.3	6.9	7.8	4.5
LMLM	1885	2415	16.7	24.2	8.9	10.0
LLHH	2275	1750	19.2	9.1	8.4	5.2
LLHM	1575	1925	17.0	13.2	10.8	6.9
LLMH	1675	1500	13.1	7.2	7.8	4.8
LLMM	1860	1405	16.7	12.4	9.0	8.8
LLLH	2695	1030	25.3	4.2	9.4	4.1
LLLL	1540	1175	13.9	6.9	9.0	5.9

Appendix Table 2. Growth Measurements for Individual Trees. Increase in Diameter, Dry Weight of Trunks, and Dry Weights of Fine and Coarse Roots

Treatment	Diameter Increase (millimeters)		Weight, Trunks (grams)		Weight, Fine Roots (grams)		Weight, Coarse Roots (grams)	
	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
NPCCa								
HHHH	2.9	4.6	30.8	58.1	22.3	23.3	67.6	81.2
HHHM	4.6	4.1	34.6	35.6	18.5	21.4	58.3	67.7
HHMH	3.1	4.0	52.1	47.7	17.3	27.8	56.4	64.5
HHMM	2.6	2.6	51.4	51.4	13.3	14.6	68.2	70.9
HHLL	1.1	0.9	36.6	31.6	7.5	13.2	63.0	38.4
HHLM	0.9	0.0	20.6	31.0	8.6	4.6	53.9	34.9
HMHH	2.2	4.1	42.9	53.3	15.9	18.1	61.2	58.3
HMHM	5.1	4.8	40.2	37.3	21.8	14.9	92.6	90.3
HMMH	3.8	1.7	55.9	38.3	25.0	15.5	58.0	50.5
HMMM	4.1	3.8	51.5	47.7	23.1	13.6	74.5	66.6
HM LH	2.2	0.5	37.6	39.4	9.2	7.3	60.7	58.4
HMLH	0.4	0.4	25.0	17.2	4.6	1.5	33.6	43.5
HLHH	0.6	1.2	43.7	48.7	9.3	12.6	64.5	61.1
HLHM	3.0	2.1	55.7	55.9	21.2	28.7	62.4	62.0
HLMH	1.1	1.4	55.0	40.2	15.8	10.1	71.1	46.1
HLMM	2.1	2.1	50.8	43.2	20.4	13.1	67.0	51.7
LLHH	0.7	0.8	36.6	43.7	12.3	8.2	56.6	58.5
LLHM	0.5	0.9	38.4	38.4	10.6	14.1	57.3	47.5
LLMH	3.4	6.6	51.4	85.0	27.3	67.7	59.1	101.7
LLMM	7.2	7.4	52.5	49.0	35.1	40.2	104.9	87.9
MHHH	7.3	4.3	76.5	61.6	31.7	21.3	88.6	97.8
MHHM	5.7	8.3	61.8	68.1	35.1	42.0	70.5	86.9
MHMH	3.9	4.6	45.7	39.3	28.9	18.9	74.3	67.2
MHMM	1.9	1.6	48.0	33.2	19.9	10.0	59.8	46.4
MMLH	7.1	5.2	72.4	65.9	23.9	21.0	103.9	88.6
MMLM	7.6	8.5	99.6	99.1	44.8	92.4	129.5	127.0
MLHH	7.3	9.0	109.4	97.9	65.3	44.4	123.1	125.2
MLHM	4.5	8.2	74.0	96.0	12.1	48.5	96.8	128.8
MLMH	4.0	3.2	42.4	43.9	13.3	16.7	71.0	61.6
MLMM	1.8	1.8	32.9	40.3	9.0	9.1	52.3	68.6
MLLH	1.7	2.4	38.9	49.9	12.6	20.9	73.7	64.6
MLLM	1.8	3.5	39.9	49.0	34.6	26.7	53.6	74.2
MMHH	1.9	3.0	29.8	40.8	17.9	22.8	78.5	64.1
MMHM	3.3	1.4	58.1	45.5	24.3	18.2	72.0	65.5
MMMH	2.4	3.0	40.5	48.5	20.0	24.9	59.8	89.3
MMML	0.7	1.2	30.7	48.1	5.5	10.9	49.8	69.0
LLHH	0.6	0.3	33.1	36.1	9.7	13.6	53.2	59.6
LLHM	0.8	0.6	34.9	36.2	16.2	28.3	59.2	52.4
LLMH	0.3	0.1	38.9	34.8	7.7	11.2	60.6	62.2
LLMM	1.0	0.7	30.4	31.5	10.9	6.7	45.0	42.5
LMLH	0.5	0.0	29.1	37.8	5.5	5.0	34.9	44.1
LMLM	0.3	0.5	42.6	43.9	4.9	9.6	61.4	64.4
LMHH	1.0	0.2	37.6	45.1	19.7	12.1	45.4	73.9
LMHM	1.6	0.8	33.3	36.3	13.8	16.2	69.3	57.6
LMMH	1.3	0.6	21.1	26.9	8.9	11.3	62.5	51.5
LMML	1.5	1.4	44.2	33.5	15.5	18.1	59.3	52.9
LLLH	0.8	0.5	44.2	37.8	8.4	5.4	63.4	47.7
LLLM	1.2	1.2	33.3	40.7	5.8	10.9	48.7	61.0
LLLH	0.9	0.5	37.5	34.3	16.1	6.8	50.0	48.1
LLLM	1.3	0.6	26.1	46.3	23.2	20.9	47.5	68.1
LLMH	0.7	0.4	43.0	29.8	20.5	15.0	60.1	50.4
LLML	1.2	1.2	32.3	36.8	8.9	11.4	63.3	57.1
LLLH	1.5	0.2	44.4	31.4	9.1	7.2	79.8	60.3
LLLM	1.6	0.4	33.1	43.9	15.9	5.8	42.2	54.6

Appendix Table 3. Nitrogen in Shoots as Percentage of Dry Weight for Individual Trees

Treatment NPKCa	Total Nitrogen (percent)		Soluble Nitrogen (percent)		Insoluble Nitrogen (percent)	
	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
HHHH	.831	1.004	.363	.465	.469	.539
HHHM	.942	1.109	.474	.599	.468	.509
HHMH	.925	.904	.439	.382	.485	.521
HHMM	.988	1.123	.526	.631	.462	.492
HHLH	1.460	1.659	.822	1.004	.637	.656
HHLM	1.536	1.565	.876	.890	.660	.674
HMHH	1.152	1.096	.604	.591	.547	.506
HMHM	.920	1.046	.449	.566	.470	.481
HMMH	1.074	1.549	.542	.917	.533	.632
HMMM	.906	1.180	.450	.687	.457	.494
HMLH	1.331	1.865	.763	1.155	.569	.710
HMIM	1.212	1.144	.601	.575	.612	.570
HLHH	1.897	1.757	1.277	1.153	.621	.605
HLHM	1.204	1.530	.684	.910	.520	.619
HLMH	1.586	1.304	1.009	.790	.578	.513
HLMM	1.089	1.117	.612	.653	.476	.464
HLLH	1.856	1.803	1.233	1.239	.623	.565
HLIM	1.083	1.196	.585	.702	.497	.493
MHHH	.792	.727	.331	.276	.460	.451
MHHM	.596	.549	.205	.156	.391	.394
MHMH	.645	.596	.218	.167	.428	.430
MHMM	.715	.615	.308	.208	.407	.407
MHLH	.818	.879	.346	.393	.473	.487
MHIM	.774	1.048	.323	.570	.451	.479
MMHH	.773	.778	.362	.332	.412	.446
MVMH	.556	.522	.173	.159	.384	.364
MMMH	.684	.599	.261	.218	.424	.381
MMMM	.751	.553	.376	.186	.376	.368
MLHH	.921	1.006	.479	.530	.441	.475
MLHM	1.069	.961	.585	.545	.485	.417
MLHH	1.266	1.089	.695	.585	.572	.503
MLHM	1.106	1.115	.607	.588	.498	.526
MLMH	1.134	1.036	.634	.544	.499	.492
MLMM	.892	1.080	.446	.618	.445	.461
MLLH	.795	.818	.363	.400	.432	.417
MLIM	1.169	1.163	.672	.624	.496	.539
LHHH	1.137	.463	.563	.106	.573	.357
LHHM	.751	.731	.258	.247	.494	.484
LHMH	.674	.458	.208	.125	.467	.332
LHMM	.721	.855	.286	.371	.435	.484
LHLH	1.003	.533	.479	.123	.525	.411
LHLM	.751	.853	.300	.385	.452	.469
LMHH	.527	.567	.140	.154	.387	.413
LMHM	.649	.781	.290	.349	.360	.433
LMMH	.602	.424	.182	.101	.419	.323
LMMM	.618	.787	.213	.303	.406	.485
LMHL	.851	.402	.344	.239	.507	.162
LMIM	.476	.492	.123	.150	.354	.342
LLHH	.617	.409	.191	.222	.426	.186
LLHM	.553	.670	.191	.209	.362	.461
LLMH	.644	.433	.183	.106	.462	.328
LLMM	.554	.660	.182	.225	.371	.435
LLLH	.467	.527	.105	.097	.362	.429
LLIM	.677	1.188	.257	.669	.420	.520

Appendix Table 4. P, K, Ca, and Mg in Shoots as Percentage of Dry Weight for Individual Trees								
Treatment	Phosphorus (percent)		Potassium (percent)		Calcium (percent)		Magnesium (percent)	
NPKCa	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
HHHH	.282	.244	.674	.591	.323	.320	.118	.125
HHHM	.236	.273	.608	.901	.093	.099	.161	.144
HHMH	.239	.284	.579	.532	.385	.435	.111	.134
HHMM	.238	.319	.548	.588	.079	.101	.202	.219
HHLH	.394	.426	.287	.250	.514	.544	.165	.184
HHLM	.364	.382	.396	.336	.114	.186	.592	.533
HMHM	.215	.167	.825	.722	.379	.289	.147	.118
HMMH	.121	.118	.709	.658	.067	.084	.117	.167
HMMM	.179	.287	.553	.573	.353	.477	.137	.211
MMHM	.135	.137	.545	.524	.103	.111	.165	.187
MMHL	.244	.361	.264	.257	.461	.632	.123	.165
MMLM	.207	.206	.406	.278	.214	.148	.393	.476
HLHH	.068	.060	.671	.643	.462	.390	.186	.147
HLHM	.042	.058	.696	.657	.080	.102	.128	.256
HLMH	.060	.052	.500	.390	.433	.322	.128	.115
HLMM	.060	.045	.356	.356	.101	.172	.173	.224
HLHL	.060	.070	.345	.360	.440	.519	.136	.105
HLML	.059	.057	.312	.361	.138	.111	.300	.309
MHHH	.201	.181	.769	.646	.516	.663	.060	.051
MHHM	.208	.195	.733	.766	.238	.222	.057	.077
MHMH	.164	.212	.522	.509	.759	.667	.065	.058
MHMM	.235	.204	.534	.453	.280	.277	.090	.132
MHLH	.257	.213	.238	.253	.648	.616	.071	.067
MHLM	.347	.217	.327	.330	.297	.287	.156	.102
MMHH	.090	.092	.455	.582	.483	.575	.052	.059
MMHM	.091	.102	.676	.626	.206	.189	.066	.082
MMMH	.082	.089	.409	.508	.629	.835	.056	.081
MMML	.102	.110	.504	.378	.236	.240	.057	.116
MMHL	.116	.145	.244	.214	.638	.667	.061	.088
MMLM	.240	.177	.335	.295	.275	.212	.147	.090
MLHH	.080	.062	.549	.642	.814	.680	.054	.048
MLHM	.062	.049	.552	.671	.228	.166	.107	.083
MLMH	.051	.061	.383	.376	.902	.885	.043	.077
MLMM	.044	.071	.425	.401	.319	.295	.113	.130
MLHL	.058	.047	.344	.326	.825	.744	.069	.062
MLLM	.106	.084	.375	.342	.373	.361	.153	.141
LHHH	.273	.101	.914	.721	1.204	.889	.095	.073
LHHM	.281	.292	.854	.847	.304	.348	.142	.134
LHMH	.251	.105	.741	.530	1.117	1.096	.088	.085
LHMM	.279	.416	.476	.728	.379	.498	.141	.131
LHLH	.237	.151	.597	.424	1.271	1.158	.095	.152
LHLM	.336	.399	.519	.565	.498	.557	.122	.176
LMHH	.187	.111	.787	.977	1.179	1.039	.086	.091
LMHM	.169	.233	.889	.874	.274	.307	.080	.106
LMMH	.207	.097	.648	.634	.989	1.115	.064	.096
LMML	.165	.249	.524	.532	.479	.492	.136	.199
LMHL	.162	.093	.454	.462	1.231	1.010	.083	.070
LMLM	.207	.157	.471	.380	.354	.361	.108	.148
LLHH	.060	.038	.763	.894	1.027	.892	.079	.067
LLHM	.085	.109	.822	.781	.229	.263	.095	.118
LLMH	.088	.058	.601	.363	1.383	1.005	.091	.106
LLMM	.060	.093	.536	.550	.309	.353	.069	.113
LLLH	.069	.056	.538	.405	.797	1.443	.070	.140
LLLM	.076	.142	.367	.456	.450	.586	.157	.212

Appendix Table 5. Nitrogen in Trunks as Percentage of Dry Weight for Individual Trees

Treatment NPKCa	Total Nitrogen (percent)		Soluble Nitrogen (percent)		Insoluble Nitrogen (percent)	
	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
HHHH	.465	.546	.198	.258	.267	.287
HHHM	.556	.665	.267	.360	.289	.306
HHMH	.511	.520	.237	.235	.274	.284
HHMM	.451	.453	.211	.206	.241	.246
HHLH	.543	.620	.283	.344	.259	.275
HHLM	.432	.376	.190	.153	.242	.224
HMHH	.578	.611	.300	.319	.278	.291
HMHM	.499	.570	.245	.301	.255	.269
HMMH	.558	.665	.267	.382	.292	.284
HMMM	.522	.615	.215	.333	.307	.283
HMLH	.626	.528	.344	.298	.282	.231
HMIM	.325	.309	.107	.109	.218	.200
HLHH	.618	.631	.345	.339	.273	.292
HLHM	.632	.669	.336	.354	.296	.314
HLMH	.546	.510	.290	.263	.256	.246
HYMM	.514	.498	.241	.229	.273	.270
HLLH	.645	.569	.359	.292	.285	.277
HLLM	.339	.462	.118	.206	.221	.256
MHHH	.413	.395	.138	.126	.276	.269
MHHM	.283	.385	.073	.124	.209	.261
MHMH	.406	.311	.138	.068	.268	.243
MHMM	.385	.383	.137	.124	.247	.259
MHLH	.394	.393	.128	.133	.267	.261
MHLM	.300	.392	.089	.164	.212	.228
MMHH	.424	.381	.181	.128	.242	.254
MVMH	.324	.324	.085	.081	.240	.242
MMMH	.392	.397	.129	.144	.263	.252
MMHM	.443	.375	.206	.124	.237	.252
MMLH	.412	.413	.173	.170	.240	.244
MMIM	.392	.367	.159	.161	.233	.207
MLHH	.483	.545	.213	.260	.270	.285
MLEM	.559	.569	.274	.267	.286	.301
MLMH	.422	.469	.184	.199	.238	.271
MLMM	.444	.446	.192	.188	.253	.259
MLLH	.375	.381	.139	.126	.235	.256
MLLM	.389	.394	.140	.145	.248	.248
LHHH	.377	.182	.142	.020	.236	.162
LHHM	.336	.312	.102	.078	.235	.234
LHMH	.274	.195	.058	.031	.215	.164
LHMH	.289	.312	.074	.089	.214	.222
LHLH	.374	.191	.127	.030	.248	.161
LHIM	.272	.303	.071	.088	.202	.216
LMHH	.292	.221	.072	.039	.220	.182
LMHM	.297	.342	.064	.109	.234	.234
LMNH	.336	.222	.099	.033	.237	.188
LMMM	.284	.393	.072	.136	.212	.258
LM LH	.282	.204	.072	.024	.210	.181
LMIM	.240	.262	.043	.053	.197	.208
LLHH	.296	.197	.075	.026	.221	.171
LLEH	.283	.286	.068	.063	.215	.223
LLMH	.288	.195	.071	.031	.216	.164
LLMM	.245	.267	.047	.060	.199	.208
LLLH	.244	.209	.029	.036	.214	.174
LLIM	.275	.328	.060	.108	.214	.221

Appendix Table 6. P, K, Ca, and Mg in Trunks as Percentage of Dry Weight for Individual Trees								
Treatment NPKCa	Phosphorus (percent)		Potassium (percent)		Calcium (percent)		Magnesium (percent)	
	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
HHHH	.167	.163	.398	.342	.288	.237	.070	.076
HHHM	.156	.133	.330	.376	.136	.115	.087	.063
HHMH	.170	.181	.296	.252	.295	.245	.080	.075
HHMM	.133	.165	.296	.276	.124	.143	.094	.101
HHLH	.160	.187	.165	.171	.288	.309	.083	.073
HHLM	.119	.132	.174	.166	.165	.160	.089	.073
HMHM	.137	.128	.410	.452	.220	.207	.070	.067
HMMH	.079	.083	.339	.330	.081	.113	.075	.075
HMMM	.131	.156	.316	.322	.215	.322	.064	.089
MMMH	.107	.100	.302	.308	.136	.126	.090	.094
MMHL	.124	.135	.181	.165	.279	.284	.060	.064
MMHM	.086	.089	.182	.154	.171	.141	.082	.078
MLHH	.060	.049	.249	.231	.201	.213	.059	.067
MLEM	.036	.049	.314	.297	.100	.192	.060	.062
MLMH	.052	.052	.174	.192	.230	.254	.051	.057
MLMM	.052	.046	.213	.213	.164	.164	.073	.077
LLHH	.054	.060	.160	.150	.245	.239	.045	.059
LLHM	.051	.055	.153	.182	.134	.144	.074	.092
MLHH	.130	.099	.374	.401	.300	.348	.048	.037
MHHM	.092	.089	.353	.393	.275	.186	.048	.059
MHHM	.099	.115	.304	.292	.341	.303	.047	.054
MHHM	.143	.135	.262	.253	.196	.213	.075	.070
MHLH	.132	.120	.208	.190	.348	.467	.061	.051
MHLM	.131	.132	.148	.161	.186	.267	.068	.059
MMHH	.078	.059	.323	.385	.284	.264	.053	.039
MMHM	.060	.080	.354	.402	.151	.162	.039	.060
MMMH	.066	.070	.262	.277	.282	.350	.043	.056
MMMM	.084	.083	.335	.297	.193	.171	.063	.054
MMHL	.079	.097	.148	.186	.335	.414	.052	.058
MMHM	.123	.106	.161	.165	.205	.179	.064	.062
MLHH	.059	.047	.292	.316	.277	.258	.050	.033
MLEM	.056	.054	.277	.324	.198	.146	.047	.054
MLMH	.041	.050	.222	.264	.311	.328	.042	.038
MLMM	.040	.073	.259	.207	.166	.181	.050	.052
MLLH	.046	.046	.209	.217	.339	.284	.040	.041
MLLM	.062	.062	.212	.211	.226	.211	.046	.050
LEHH	.114	.075	.360	.313	.284	.196	.047	.039
LEHM	.122	.132	.354	.380	.175	.230	.050	.057
LEMH	.120	.073	.312	.228	.277	.254	.046	.032
LEMM	.123	.152	.246	.297	.218	.242	.060	.054
LHLH	.122	.087	.233	.204	.328	.262	.046	.055
LHLM	.124	.126	.196	.240	.230	.205	.057	.062
LHHM	.091	.080	.338	.314	.337	.258	.044	.050
LMHH	.091	.108	.377	.372	.211	.183	.048	.064
LMHM	.105	.077	.275	.298	.337	.299	.050	.050
LMMH	.091	.125	.284	.275	.267	.235	.048	.067
LMML	.073	.065	.254	.120	.339	.220	.049	.044
LMHL	.087	.089	.100	.190	.222	.233	.053	.072
LLHH	.054	.041	.302	.310	.312	.234	.048	.046
LLHM	.055	.059	.379	.357	.183	.186	.045	.050
LLMH	.063	.042	.240	.272	.318	.271	.043	.042
LLMM	.060	.052	.238	.210	.190	.187	.060	.047
LLLH	.058	.047	.228	.212	.312	.262	.045	.058
LLLM	.056	.065	.237	.165	.243	.218	.057	.064

Appendix Table 7. Nitrogen in Leaves as Percentage of Dry Weight for Individual Trees

Treatment NPKCa	Total Nitrogen (percent)		Soluble Nitrogen (percent)		Insoluble Nitrogen (percent)	
	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
HHHH	3.742	3.787	.283	.487	3.478	3.300
HHHM	3.511	3.317	.284	.465	3.226	2.863
HHMH	3.550	3.431	.296	.373	3.255	3.057
HHMM	3.388	3.209	.287	.403	3.102	2.805
HHLH	3.942	3.778	.651	.545	3.291	3.232
HHLM	2.825	2.574	.208	.390	2.616	2.183
HMHH	3.386	3.469	.328	.416	3.057	3.052
HMHM	3.234	3.318	.285	.402	2.948	2.915
HMMH	3.559	3.414	.272	.457	3.286	2.957
HMMM	3.231	3.228	.274	.378	2.957	2.849
HMLH	3.918	3.861	.588	.461	3.329	3.399
HMLM	2.665	2.525	.343	.139	2.323	2.386
HLHH	3.578	3.552	.457	.664	3.122	2.888
HLHM	3.675	3.728	.357	.520	3.317	3.207
HLMH	3.701	3.509	.643	.713	3.057	2.796
HLMM	3.348	3.485	.432	.460	2.915	3.024
HL LH	3.832	3.584	.416	.448	3.415	3.136
HL LM	2.957	3.083	.186	.283	2.771	2.799
MHHH	3.611	3.422	.289	.318	3.321	3.104
MHHM	3.176	3.113	.214	.292	2.961	2.822
MHMH	3.367	3.496	.239	.256	3.127	3.240
MHMM	3.310	3.187	.286	.278	3.024	2.908
MHLH	3.440	3.562	.476	.302	2.964	3.259
MHLM	3.348	3.457	.459	.293	2.889	3.165
MMHH	3.374	3.603	.337	.273	3.036	3.329
MMHM	3.214	3.197	.320	.303	2.893	2.894
MMMH	3.338	3.282	.268	.297	3.069	2.984
MMMM	3.287	3.259	.311	.320	2.975	2.938
MM LH	3.342	3.334	.362	.175	2.980	3.160
MM LM	3.307	3.364	.325	.717	2.982	2.647
MLHH	3.357	3.256	.183	.314	3.175	2.943
MLHM	3.352	3.275	.209	.271	3.142	3.005
MLMH	3.532	3.261	.567	.264	2.964	2.996
MLMM	3.307	3.042	.332	.157	2.974	2.884
ML LH	3.206	2.976	.249	.303	2.957	2.673
ML LM	2.970	3.069	.174	.210	2.797	2.858
LHHH	3.003	1.615	.320	.155	2.684	1.459
LHHM	2.219	2.176	.190	.143	2.028	2.032
LHMH	3.148	1.513	.185	.137	2.962	1.375
LHMM	2.557	2.872	.167	.266	2.389	2.605
LHLH	3.243	1.850	.191	.205	3.052	1.646
LHLM	2.723	2.563	.333	.287	2.390	2.275
LMHH	2.211	1.773	.210	.267	2.001	1.505
LMHM	2.033	2.416	.198	.116	1.836	2.300
LMMH	2.716	1.930	.161	.184	2.556	1.746
LMMM	2.253	2.405	.146	.205	2.108	2.201
LM LH	3.118	1.448	.152	.177	2.965	1.272
LM LM	2.391	2.567	.212	.199	2.179	2.367
LLHH	2.464	1.458	.197	.137	2.268	1.322
LLHM	2.549	2.432	.183	.195	2.366	2.237
LLMH	2.366	1.717	.195	.131	2.170	1.585
LLMM	2.677	2.414	.162	.139	2.514	2.276
LLLH	2.678	1.904	.142	.196	2.537	1.707
LLLM	2.779	2.707	.200	.202	2.578	2.505

Appendix Table 8. P, K, Ca, and Mg in Leaves as Percentage of Dry Weight for Individual Trees

Treatment NPKCa	Phosphorus (percent)		Potassium (percent)		Calcium (percent)		Magnesium (percent)	
	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
HHHH	.398	.366	3.320	3.060	1.122	1.196	.526	.535
HHHM	.348	.385	3.300	3.000	.428	.374	.776	.629
HHMH	.384	.386	2.315	1.965	1.358	1.540	.585	.716
HHMM	.329	.361	2.135	2.070	.516	.456	1.205	1.025
HHLH	.517	.515	.600	.815	1.458	1.282	.805	.628
HHLM	.296	.282	.740	.840	.930	.802	1.829	2.020
HMHH	.259	.224	3.020	3.180	1.176	1.166	.728	.738
HMHM	.205	.173	3.150	3.220	.410	.438	.657	1.025
HMMH	.238	.303	2.010	2.135	1.532	1.368	.840	.864
HMMM	.198	.183	2.010	1.960	.474	.502	.864	1.180
HMLH	.351	.357	.650	.890	1.476	1.647	1.046	.986
HMLM	.188	.176	.740	.785	.886	.994	1.910	1.940
HLHH	.117	.117	3.355	3.080	1.732	1.652	.859	.997
HLHM	.110	.119	3.530	3.370	.512	.474	1.037	.966
HLMH	.150	.137	1.830	1.695	1.688	1.406	.976	.773
HLMM	.121	.122	1.930	2.005	.792	.738	1.283	1.290
LLHH	.129	.124	.840	.704	2.084	2.000	1.267	1.123
LLHM	.130	.124	.980	.960	1.004	.956	1.902	1.930
LLMH	.375	.315	3.975	4.070	1.204	1.260	.531	.541
LLMM	.339	.382	4.445	4.045	.712	.720	.452	.434
MLHH	.362	.479	2.500	2.635	2.416	1.732	.395	.446
MLHM	.422	.388	2.835	2.600	.986	1.040	.477	.666
MLMH	.925	.517	.710	.670	1.806	1.650	.495	.498
MLLM	.847	.596	.695	.840	1.022	1.250	.685	.782
MMHH	.179	.199	3.520	3.985	1.140	1.036	.368	.318
MMHM	.185	.176	4.120	4.260	.684	.728	.396	.505
MMMh	.178	.234	2.545	2.215	1.560	2.040	.507	.584
MMVM	.205	.202	2.700	2.360	.876	1.158	.495	.773
MLLH	.240	.272	.705	.905	1.586	1.834	.585	.575
MLLM	.302	.303	1.080	.762	.994	1.032	.753	.568
MLHH	.149	.108	3.995	3.450	1.576	1.432	.452	.426
MLHM	.153	.142	3.980	3.895	.674	.710	.443	.459
MLMH	.130	.134	2.455	2.790	1.942	2.040	.452	.536
MLMM	.126	.140	2.450	2.575	1.186	1.204	.711	.720
MLLH	.134	.127	1.665	1.300	2.460	2.340	.535	.575
MLLM	.158	.144	2.115	1.285	1.742	1.734	1.030	1.160
LLHH	.520	.310	4.165	4.375	1.880	1.928	.485	.484
LLHM	1.068	1.770	4.300	4.315	1.168	1.048	.789	.683
LLMH	.453	.332	3.650	2.925	2.010	2.216	.384	.547
LLMM	.810	.621	2.660	2.655	1.540	1.740	.819	.937
LHLH	.363	.407	2.770	2.480	2.384	2.600	.567	.618
LHLM	.860	.969	2.170	1.760	2.024	2.170	.946	1.218
LHHM	.755	.330	3.990	4.875	2.016	2.260	.358	.567
LHMH	.603	.626	4.520	4.315	1.006	1.204	.485	.706
LHMM	.427	.172	3.490	2.480	2.380	2.480	.523	.680
LMHH	.407	.626	2.895	2.985	1.780	1.732	.907	1.012
LMHM	.274	.346	2.300	2.185	2.662	2.200	.652	.578
LMMH	.478	.310	1.615	1.720	1.762	1.968	.870	1.061
LMMM	.145	.110	3.730	4.625	2.034	1.506	.574	.473
LLEH	.181	.176	4.550	4.880	1.022	.940	.664	.632
LLEH	.152	.139	2.865	2.935	2.740	2.376	.549	.657
LLEH	.156	.162	2.850	2.515	1.430	1.680	.754	.972
LLEH	.175	.263	2.375	4.135	2.716	2.070	.664	.686
LLEH	.163	.170	1.920	1.990	1.954	1.938	1.160	.972

